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CRASHWORTHINESS DESIGN PARAMETER SENSITIVITY ANALYSIS.(U)

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CRASHWORTHINESS DESIGN PARAMETER SENSITIVITY ANALYSIS

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Fort Eustis, Va. 23604

APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report contains reasonable comparative estimates for incremental weights and costs of incorporation of crashworthy crew seats, troop seats, landing gear, and structure into Army helicopters. It provides data on a metallic baseline aircraft and a composite aircraft in the 5000- to 6000-pound category that yields a valid comparison between the two methods of construction. While the final answers are not exact in nature, the comparisons are valid. The data is presented for various percentiles of MIL-STD-1290.

Mr. George Singley III and Mr. Gordon T. Galow of the Safety and Survivability Technical Area served as technical monitors on this contract.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This program investigated the relationships between aircraft weight, the level of crashworthiness in the design, and the cost and weight associated with crashworthiness elements of the design. Accident and research data were reviewed and actual aircraft designs were analyzed with respect to their levels of crashworthiness and potential improvements.

Processing of the data yielded cost and weight curves for use in preliminary design. The curves provide the relationships between gross weight, mean empty weight, levels of crashworthiness, and selected design elements that contribute

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to crashworthiness for designs employing metallic or composite materials and having gross weights up to 50,000 pounds.

Comparisons were made with the current ACAP analyses and results showed good agreement for the weight values and level of crashworthiness.

The intent of the curves is to allow the designer to rapidly optimize the weights of a preliminary design with respect to performance and utility, and to assess the impact on crashworthiness of reducing the weight of the structure or other crashworthiness contributions. When weight values are resolved, cost curves are then used.

A "Scout" helicopter was defined for both a metallic and composite structure and comparisons were made using the curves generated in this report.

PREFACE

This technical report concludes Phases I, II and III of the Crashworthiness Design Parameter Sensitivity Analysis Program conducted for the Applied Technology Laboratory, U. S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia, by the Boeing Vertol Company under contract DAAK51-79-C-0042.

Mr. Gordon T. Galow was the Army Project Engineer and Dr. James Hicks and Mr. Ronald Reynolds of the U. S. Army Safety Center, Fort Rucker, Alabama, provided assistance in the review of accident data and reports.

The program was conducted under the technical direction of Mr. Joseph E. Gonsalves, Program Manager. Principal contributors were Anthony Tanner, Project Engineer, Nikolaos Caravasos, Stephen Blewitt, John Schneider, Arling Schmidt and Stanley Mills.

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INTRODUCTION

Significant increases in the crashworthiness of current and next-generation helicopters have been achieved in comparison to helicopters designed prior to the development of the USAAMRDL TR 71-22 "Crash Survival Design Guide". Principles of this design guide are now incorporated into MIL-STD-1290 which new Army light fixed- and rotary-wing aircraft are required to meet. The increased crashworthiness of the AAH and UTTAS has been shown to be practical, cost-effective, and will significantly increase the combat effectiveness of the future fleet by conserving combat resources, both manpower and material. The impact of these crashworthiness features on the weight and cost of the AAH and UTTAS has been documented.

This report documents the study effort directed toward minimizing the adverse impact of crashworthiness design criteria on the cost, weight and performance of future Army helicopter designs. The effects of crashworthiness cost drivers are identified which will assist in determining R&D efforts necessary to reduce the cost of incorporating crashworthiness into future helicopter designs without reducing the level of crash impact protection specified in MIL-STD-1290.

Trend data were developed for crashworthiness cost and weight as a function of helicopter weight and level of crashworthiness obtained. Both metal and composite airframe structures were investigated. Cost and weight drivers evaluated included the following:

- Crew seat system
- Troop seat system
- Landing gear
- Postcrash fire prevention
- Emergency egress
- Airframe crashworthiness

The study was undertaken in three phases as follows:

Phase I - Analysis of the Effect of Crashworthiness Requirements on Existing Helicopters

Actual crash information was obtained from the U. S. Army Safety Center, Fort Rucker, Alabama, and specific accident reports were reviewed at that facility for five aircraft types ranging from the OH-6A to the CH-47C. Trends were obtained for the distributions of survivable accidents with respect to impact velocities, and these data (in conjunction with a listing of injury casual factors) were used to assess the crashworthiness capabilities of the aircraft. Where available, published literature was used to provide additional information to obtain a better understanding of accident conditions. Cost data, where available, also was compiled.

Phase II - Parametric Sensitivity Analysis

The weight and cost data generated in Phase I were used to develop cost and weight drivers for relevant crashworthiness features. Features considered were crew and troop seats, landing gear, airframe, postcrash fire prevention, and emergency egress.

Cost weight and resulting benefits as functions of various levels of crashworthiness were generated for the specific aircraft studied; improvements were incorporated into the existing designs; and revised crashworthiness assessments were made. Trend curves were generated for cost and weight changes in crashworthiness levels expressed as variations in aircraft gross weight.

Phase III - Scout Helicopter Crashworthiness Analysis

Preliminary designs were generated for two "Scout" aircraft of metallic and composite construction with a mission gross weight less than 10,000 pounds. The designs provided maximum protection in a crash environment for crew and advanced avionics/visionics equipment.

Cost and weight benefits were estimated using the curves generated in Phase II, including acquisition and life-cycle costs.

Recommended changes to MIL-STD-1290 were identified and presented at the conclusion of this study.

LITERATURE AND DATA SURVEY

SURVEY OBJECTIVES

The objectives of the Survey were:

- to assess the crashworthiness capabilities of selected helicopter designs
- to define desirable crashworthiness levels for certain applications
- to define methods of achieving structural crashworthiness
- to determine the costs of various kinds of accidents by helicopter type
- to identify the economic benefits of MIL-STD-1290 features and to analyze studies which project savings for their incorporation.

LITERATURE SURVEY

In the original RFP, 14 reports were listed for review. Thirteen reports were available, but USARTL TR 79-22 was not published during the timeframe of this study although some chapters were reviewed in draft form.

Additional reports were reviewed and/or compiled for use during the study phases of this program.

Each report is summarized here to acquaint the reader with the salient contents.

"Light Fixed-and Rotary-Wing Aircraft, Crashworthiness", MIL-STD-1290 (AV) January, 1974 (Reference 1)

This document defines the U. S. Army minimum crashworthiness design criteria for light fixed-wing and rotary-wing aircraft.

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1 MILITARY STANDARD, MIL-STD-1290 (AV), LIGHT FIXED-AND-ROTARY WING AIRCRAFT CRASHWORTHINESS, Department of Defense, Washington, D. C., 20301, 25 January 1974.

Documentation, definitions, and design requirements are given for all aircraft systems where crashworthiness is applicable.

Design pulses, occupant space requirements, and specific design problems that must be addressed are identified so that the final aircraft configuration is designed to prevent occupant fatalities and to minimize the number and severity of occupant injuries during crash impacts of severity up to and including the 95th percentile potentially survivable accident. In addition, aircraft damage must be minimized to the maximum extent practical when considered in conjunction with occupant survival requirements.

Detailed requirements are itemized for the following:

- airframe crashworthiness - airframe, landing gear and large mass attachments
- occupant retention - seats and litters
- cargo and equipment retention
- postcrash emergency escape
- postcrash fire prevention.

<u>"Aircraft Crash Survival Design Guide", USARTL-TR-79-22, to be published. (Reference 2)</u>

This is the fourth revision of the "Crash Survival Design Guide" first published in 1967. The third revision, USAAMRDL-TR-71-22, published in October 1971, was the basis for the criteria contained in MIL-STD-1290 (AV) (Reference 1), the crashworthiness military standard for the U.S. Army.

This new edition of the design guide is to be published in five volumes:

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[2] Laananen, D. H., et al., AIRCRAFT CRASH SURVIVAL DESIGN GUIDE, Volumes I-V, Simula, Inc.; USARTL Technical Reports 79-22A, 79-22B, 79-22C, 79-22D, 79-22E, Applied Technology Laboratory, U. S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia, 1980, AD A093784, A082512, A089104, A088441, A082513.

Volume I - Design Criteria and Checklists

Pertinent criteria extracted from Volumes II through V, presented in the same order in which they appear in those volumes.

Volume II - Aircraft Crash Environment and Human Tolerance

Crash environment, human tolerance to impact, military anthropometric data, occupant environment, test dummies, and accident information retrieval.

Volume III - Aircraft Structural Crashworthiness

Crash load estimation, structural response, fuselage and landing gear requirements, rotor requirements, ancillary equipment, cargo restraints, and structural modeling.

Volume IV - Aircraft Seats, Restraints, and Litters

Operational and crash environment, energy attenuation, seat design, litter requirements, restraint system design, and occupant/restraint system/seat modeling.

Volume V - Aircraft Postcrash Survival

Postcrash fire, ditching, emergency escape, and crash locator beacons.

"Engineering Analysis of Crash Injury in Army OH-58A Aircraft", USASC-TR-79-1, January 1979. (Reference 3)

One hundred sixty-three major accidents that occurred in CY 1971-1976 were reviewed and analyzed.

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[3] ENGINEERING ANALYSIS OF CRASH INJURY IN ARMY OH-58A AIRCRAFT, USASC-TR-79-1, U.S. Army Safety Center, Fort Rucker, Alabama, 36362, January 1979.

The analysis summarized the extent and underlying causes of crash injuries based on medical and engineering data contained in accident reports and related files. Vertical and longitudinal impact velocity changes and 'G' levels were plotted to assist in assessing occupant survivability potential when considered in conjunction with the injury mechanisms identified and the frequency of distribution on the occupants.

Crash hazards which resulted in the greatest personnel losses were identified and prioritized to determine pressing crashworthiness research and development programs. The impact conditions under which crash hazards resulted in preventable injuries were summarized to aid in future determination of crashworthiness design criteria.

Twenty crash hazards were identified; of these, 17 may reasonably be influenced by crashworthiness design.

A major problem was the occupant protection in vertical impacts which was deemed to be inadequate for impact velocities in excess of 15 to 20 ft/sec. The incidence of spinal injuries increases sharply for impact velocities in excess of 20 ft/sec. Taking into consideration the landing gear design sink speed of 12 ft/sec it can be deduced that the underfloor structure and crew seat combination does not offer much energy attenuation.

Recommendations made for future research and development to provide the greatest benefits in reducing crash hazards were:

- improved vertical energy absorption in the aircraft structure and/or crew seats.

- crew member restraint systems with improved upper torso restraint.

- overhead structure to act as a main rotor blade deflector.

In addition, it was recommended that an improved method be implemented for estimating crash impact conditions. This is needed for accurate determination of future crashworthiness design criteria.

"Engineering Analysis of Crash Injury in Army CH-47 Aircraft", USAAAVS-TR-78-4, June 1978 (Reference 4)

This was a similar study to that performed in Reference 3 for the OH-58A aircraft to identify potential design improvements with respect to crashworthiness and occupant injury causal factors.

CY 1971-1976 again was the time frame for the study, and from a sample of 29 accidents 16 crash hazards were identified; of these 13 may reasonably be influenced by crashworthiness design.

It was noted that significant back injuries do not occur for vertical impact velocities of less than 25 ft/sec.

Improvements which would result in the greatest benefits in reducing hazardous conditions for occupants are:

- seats for enlisted crewmembers which permit their usage during critical portions of the flight.
- passenger seats with improved structural integrity.
- transmission oil containment with improved postcrash fire protection.

The recommendations were made also with respect to improved estimation of impact conditions.

4 ENGINEERING ANALYSIS OF CRASH INJURY IN ARMY CH-47 AIRCRAFT, USAAAVS-TR-78-4, U.S. Army Agency for Aviation Safety, Fort Rucker, Alabama, 36362, June 1978.

"Engineering Analysis of Crash Injury in Army AH-1 Aircraft," USAAAVS-TR-78-3, March 1978 (Reference 5)

This was a similar study to those described in References 3 and 4, with CY 1971-1976 being the time frame. 141 major accidents were reviewed and 18 separate crash hazards were identified.

Significant numbers of back injuries were identified when vertical impact velocity changes of less than 20 ft/sec occurred.

Improvements which would result in the greatest benefits in reducing hazardous conditions for occupants are:

- energy-absorbing crew seats
- overhead structure to act as a main rotor blade deflector.
- crew restraint system with improved upper torso restraint.

Additional research requirements suggested by the study were:

- an improved spinal injury model which considers multidirectional crash forces.
- a crash data recording system to provide accurate determination of impact conditions.

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5 ENGINEERING ANALYSIS OF CRASH INJURY IN ARMY AH-1 AIRCRAFT, USAAAVS-TR-78-3, U.S. Army Agency for Aviation Safety, Fort Rucker, Alabama, 36362, March 1978

Carnell, B.L., "Crashworthiness Design Features for Advanced Utility Helicopters," Aircraft Crashworthiness, October 1975, pp 51-63 (Reference 6)

This paper defines six phases that occur during a crash sequence and identifies the potentially hazardous failure modes and subsequent events that may occur. For comparison, features of the Sikorsky YUH-60A included to prevent or minimize occupant injury potential are described.

The six phases of the crash sequence are summarized in tabular form. These emphasize the effects of landing gear collapse, structural collapse, fuel leakage, ignition sources, fire and post-impact egress. Hazards are listed and desirable design features identified to minimize them. The YUH-60A aircraft is used as an example to identify the implementation of such design features.

Cost-effectiveness studies were made for the YUH-60A assuming a fleet of 1000 aircraft, each flying 900 hours per year.

It was estimated that during a 10-year period, 80 serious injuries would be prevented and 200 lives saved, representing a monetary value of $20 million.

The use of a crashworthy fuel system was estimated to save $22 million in material costs and an improved landing gear and structure an additional $36 million in material costs.

This represents a total cost savings of $78 million. The break-even point is reached in 2.7 years when the average use per aircraft is 2500 hours.

It was concluded that the application of crash survival design features to utility helicopters is cost effective.

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6 **Carnell, B.L., CRASHWORTHINESS DESIGN FEATURES FOR ADVANCED UTILITY HELICOPTERS**, Aircraft Crashworthiness, University Press of Virginia, P.O. Box 3608, Charlottesville, Virginia, 22903, October 1975, pp. 51-63.

Bainbridge, R.E., et al, "Crashworthiness of the Boeing Vertol UTTAS," Aircraft Crashworthiness, pp 65-82, October 1975 (Reference 7)

Since the Boeing Vertol UTTAS and the Sikorsky YUH-60A were designed to satisfy the same U.S. Army requirements, the discussion in this document is similar in content to that given in Reference 6.

Landing gear, structure, 'G' level limitation, postcrash fire minimization and postcrash egress are discussed. Solutions to these problems are similar to those proposed in Reference 6, although some design differences do occur.

Figure 1 shows the crashworthy features of the utility helicopters as incorporated on the Boeing Vertol UTTAS.

One major difficulty discussed is the ability to adequately predict the structural collapse mechanisms during the preliminary design phase of a project. At this time in a program insufficient structural information and/or system distributions data exist to allow computer analyses to be made. For this reason it was necessary to develop an approach which could readily be used during the preliminary design phase of a program. The approach finally adopted was to assume the airframe structure in the collapse mode to have characteristics similar to a landing gear; that is a load/stroke capability coupled with an efficiency factor:

$$\text{Structural Efficiency Factor} = \frac{\text{Actual Work Done}}{\text{Theoretical Capability}}$$

Detailed examination of typical helicopter airframes in controlled or known crash environments yielded Structural Efficiency Factors between 0.63 and 0.46 for an average value of 0.54. It should be noted that these values were for airframes which were not designed to meet specific crashworthiness criteria.

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[7] Bainbridge, R.E., et al, CRASHWORTHINESS OF THE BOEING VERTOL UTTAS, Aircraft Crashworthiness, University Press of Virginia, P.O. Box 3608, Charlottesville, Virginia, 22903, October 1975, pp. 65-82.

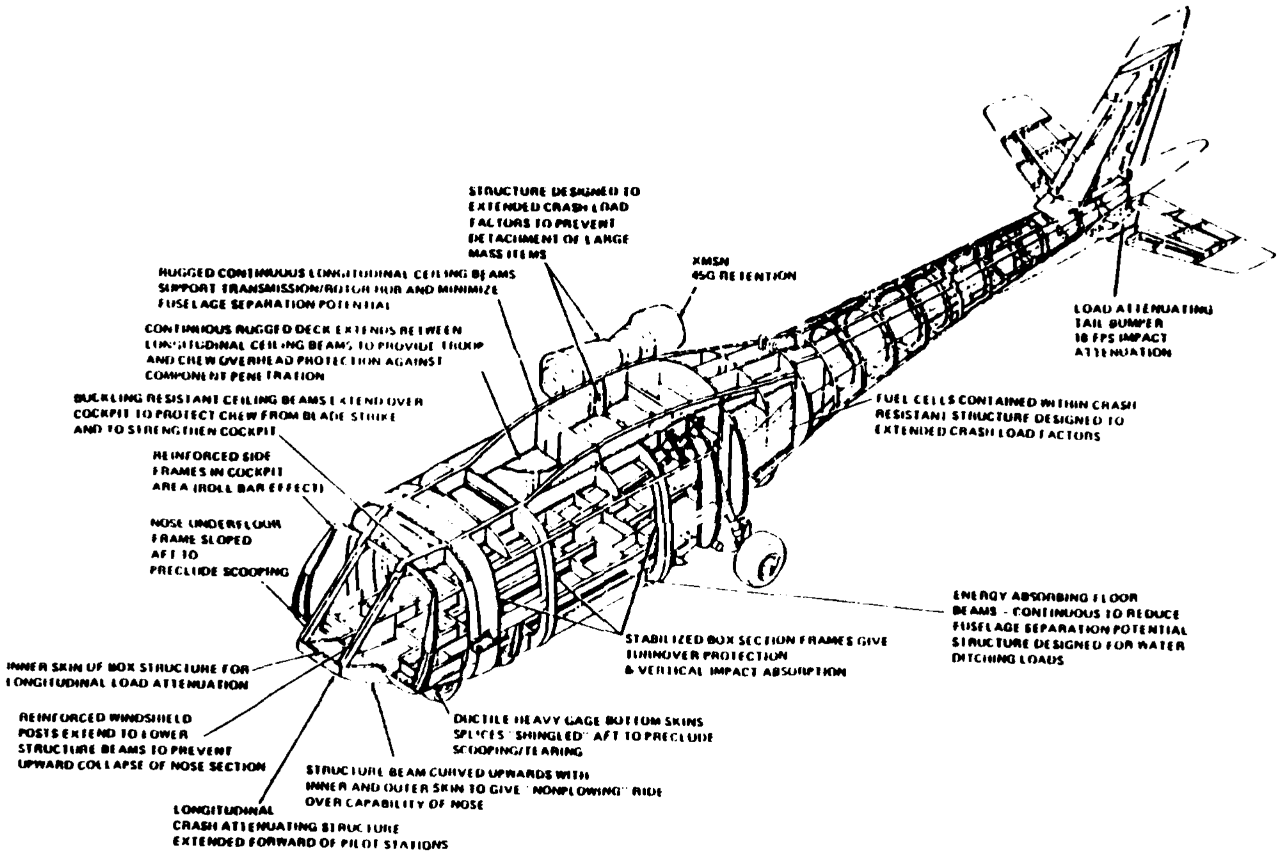

Figure 1. Crashworthy features of Boeing Vertol UTTAS.

Table 1 shows the involvement of crashworthy design features in satisfying the requirements specified.

A weight increment study showed that an additional 161 pounds of weight was needed, excluding the fuel system, to upgrade a noncrashworthy aircraft to one that met the requirements of MIL-STD-1290 (AV).

It was concluded that crash survival can be built into a design in conjunction with other requirements with little, if any, impact on cost or weight, providing an integrated design approach is used from the beginning of the program.

Haley, J.L. and Hicks, J.E., "Crashworthiness Versus Cost: A study of Army Rotary Wing Aircraft Accidents in Period January 1970 through December 1971," presented at the Aircraft Crashworthiness Symposium, University of Cincinnati, 6-8 October, 1975. (Reference 8)

This study analyzes accident data for five types of helicopters with the following purposes in mind:

- identification of injury cause factors which prevail in serious crashes
- comparison of cost and benefits of potential crash safety features for occupant protection in serious crashes.

The helicopters selected for the study cover a wide range of gross weight conditions: OH-6, OH-58, UH-1, AH-1 and CH-47.

Potentially preventable injury mechanisms are identified along with their associated costs.

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[8] Haley, J.L., and Hicks, J.E., CRASHWORTHINESS VERSUS COST: A STUDY OF ARMY ROTARY WING AIRCRAFT ACCIDENTS IN PERIOD JANUARY 1970 THROUGH DECEMBER 1971, presented at the Aircraft Crashworthiness Symposium, University of Cincinnati, Ohio, October 1975.

TABLE 1. INVOLVEMENT OF CRASHWORTHY DESIGN FEATURES

CRASHWORTHY FEATURE / REQUIREMENT	STRUCTURE				SEATS									LANDING GEAR		FUEL SYSTEM		
					CREW			TROOP			GUNNER							
	MASS ITEM RETENTION	ANTI-PLOWING NOSE DESIGN	ROLL BAR COCKPIT POSTS	ROLL BAR SIDE FRAMES	VERTICAL	LONGITUDINAL	LATERAL	VERTICAL	LONGITUDINAL	LATERAL	VERTICAL	LONGITUDINAL	LATERAL	NOSE	MAIN	CRASHWORTHY FUEL CELL	SEAL-ON-BREAKAWAY LINE FITTINGS	SLACK FLAMMABLE FLUID LINES
42 FPS 3 POINT	●				●			●			●			●	●	●	●	●
42 FPS 15 NOSE UP	●				●			●			●				●	●	●	●
15 NOSE DOWN			●		●			●			●			●				
42 FPS 30 ROLL	●			●	●		●	●		●	●		●		●	●	●	●
20 FPS INTO WALL	●	●	●			●			●			●				●	●	●
40 FPS INTO WALL	●	●	●			●			●			●				●	●	●
50 FPS 24G IMPULSE	●	●	●			●			●			●				●	●	●
ROLL OVER	●			●			●			●			●			●	●	●
PLOWING	●	●	●	●		●			●			●		●		●	●	●
PITCH OVER	●	●	●			●			●			●		●		●	●	●
LATERAL 30 FPS	●			●			●			●			●			●	●	●

Preventable losses are estimated and assessed with respect to injury prevention or minimization and hardware associated with design changes. Life-cycle costs involved in the implementation of design improvements are compared with the potential benefits that acrue with respect to hardware and personnel losses.

The results of the injury minimization and cost optimization studies were used to assess the impact of crashworthiness implementation on the UTTAS program, and a cost savings per flight hour was computed.

It was concluded that the implementation of crashworthiness requirements into the UTTAS helicopter would be cost effective with the most worthwhile features being:

- improved occupant restraint
- fuselage rollover protection
- improved landing gear
- Load-limiting seats and attenuating structure
- crashworthy fuel system

Hicks, J.E., "Economic Benefits of Utility Aircraft Crashworthiness," USAAAVS-TR-76-2, July 1976. (Reference 9)

This study was undertaken to analyze the effects of crashworthiness and other design features on aircraft life-cycle costs. The analysis was performed to provide information to supplement the evaluation of the aircraft candidates in the UTTAS Cost and Operational Effectiveness Analysis (COEA). The aircraft studied were the UH-1H, UH-1H (PIP), UH-1N, UH-1N (MOD), Bell Model 214A (MOD) and the generic UTTAS.

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9 Hicks, J.E., ECONOMIC BENEFITS OF UTILITY AIRCRAFT CRASHWORTHINESS, USAAAVS-TR-76-2, U.S. Army Agency for Aviation Safety, Fort Rucker, Alabama, 36362, July 1976.

All major accidents, regardless of cause, were analyzed for the UH-1H aircraft for the time period January 1972 through December 1975. Relative benefits of increased levels of crashworthiness were assessed and projections made for each COEA candidate for a 20-year period of peacetime operation. Accident losses were projected for both personnel losses and aircraft damage.

The results indicated a significant reduction in both accident rate and total loss due to accidents for the generic UTTAS relative to the other COEA candidates; 2.90 per 100,000 flight hours and $115 million for the UTTAS compared with the next best candidate values of 4.86 and $265 million (UH-1H).

The following conclusions were made as a result of this study:

- accidents constitute a significant portion of aircraft life-cycle costs

- crashworthiness improvements and other safety features are most efficiently included in an aircraft as integral system requirements.

- in comparison with other COEA candidates, the UTTAS will have fewer accidents and reduce the frequency of personnel injury.

- the total economic losses due to accidents for a 20-year period of operation are substantially lower for the UTTAS, $155 million, compared with the candidates whose values range from $256 million for the UH-1H to $437 million for the Bell Model 214A (MOD).

<u>"The Economic Benefits of Crashworthiness and Flight Safety Design Features in Attack Helicopters", USAAAVS-TR-77-2, June 1977.</u> (Reference 10)

This study was undertaken to establish expected economic losses due to accidents for a number of candidate aircraft that may have potential use as a future attack helicopter. The candidate aircraft were AH-1J, AH-1S, AH-1T and YAH-64.

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[10] THE ECONOMIC BENEFITS OF CRASHWORTHINESS AND FLIGHT SAFETY DESIGN FEATURES IN ATTACK HELICOPTERS, USAAAVS-TR-77-2, U.S. Army Agency for Aviation Safety, Fort Rucker, Alabama, 36362, June 1977.

For each aircraft an accident rate and mean cost value were established after taking into consideration the particular crashworthiness features of each design. Computation of accident costs showed the YAH-64 to be approximately one-half of the values for competitor aircraft and projected casualties were two-thirds.

The following conclusions resulted from the study:

- accidents constitute a significant portion of aircraft life-cycle costs.

- crashworthiness improvements are most efficient when integrated during the conceptual design phase.

- compared to other aircraft the YAH-64 should have fewer accidents and lower total accident losses.

- improved crashworthiness gives the YAH-64 a clear advantage over the AH-1J and other candidate designs.
- the total accident losses for 20 years of operation range from $176 million for the YAH-64 to $437.6 million for the AH-1T.

Hicks, J.E., "An analysis of Life Cycle Accident Costs for the Advanced Scout Helicopter," USAAAVS, January 1977 (no report number). (Reference 11)

Several aircraft were assessed as to their suitability for use as a scout. (OH-58A, OH-58C (MOD), OH-6A (MOD), BO-105, AH-1S, ASH (single) and ASH (twin).) Accident rates were established for each candidate aircraft. This was done by using the OH-58A as a baseline aircraft and modifying the accident rate of the OH-58A to account for design differences in the other candidate aircraft.

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11 Hicks, J.E., AN ANALYSIS OF LIFE CYCLE ACCIDENT COSTS FOR THE ADVANCED SCOUT HELICOPTER, USAAAVS (no report number), U.S. Army Agency for Aviation Safety, Fort Rucker, Alabama, 36362, January 1977.

Using a twenty-year period the accident rate projections varied from 8.25 per 100,000 flight hours for the OH-58A to 4.08 for the ASH (twin).

The major factor affecting these values is the twin-engine configuration with substantial single engine-out performance.

The projected life-cycle accident costs for the ASH (twin) and OH-58A are $80.6 million and $125 million respectively. These values represent a significant portion of the total life-cycle costs.

Projected accident cost and casualties are presented in graphical format.

Conclusions obtained from the study were:

- crashworthiness can reduce life-cycle costs.
- crashworthiness should be integrated into an aircraft during the conceptual design stage
- the ASH (twin) should have fewer accidents and lower total accident losses.
- improved crashworthiness produces a clear advantage of the ASH (twin) over other candidate aircraft.
- the total ASH (twin) savings compared to the OH-58A show a reduction in accident losses of 35 percent or $43 million over a twenty-year period of operation.
- a significant portion of the total losses projected for each candidate aircraft is due to crash damage to mission equipment electronics.
- the ASH design is in its preliminary stages and complete information was not available. Assumptions were made which may need correcting as the final ASH design evolves.

McDermott, J.M., & Vega, E., "The Effects of Latest Military Criteria on the Structural Weight of the Hughes Advanced Attack Helicopter - YAH-64," AHS Journal, Volume 23, Number 4, October 1978, pp 2-9. (Reference 12)

This report discusses the YAH-64 aircraft and the effects of design requirements for crashworthiness and ballistic protection. Crashworthiness requirements as defined by TR 71-22 and the systems approach used to integrate them into the design are discussed. The expected performance of individual elements is computed (landing gear, rotor system and fuselage), and the weight impact of implementing crashworthiness is tabulated. It was estimated that the empty weight of the YAH-64 increases by 3.7 percent when crash protection features are incorporated into the design.

Civilian applications of the crash protection provisions are also discussed.

In comparison to crashworthiness weight deltas, the additional weight needed to satisfy the ballistic tolerance and fail-safety requirements results in an empty weight increase of 7.3 percent.

The approach to crashworthiness may appear to be conservative, 95th percentile velocity with the 95th percentile occupant and the aircraft at maximum gross weight impacting vertically onto a rigid surface. However, it was concluded that this conservatism can be tempered by the knowledge that increased nap-of-the-earth missions may change the impact velocity distributions. The protection afforded expensive equipment, such as

[12] McDermott, J.M., and Vega, E., THE EFFECTS OF LATEST MILITARY CRITERIA ON THE STRUCTURAL WEIGHT OF THE HUGHES ADVANCED ATTACK HELICOPTER-YAH-64, American Helicopter Society Journal, Volume 23, Number 4, October 1978, pp. 3-9.

TADS/PNVS, by designing the landing gear to prevent ground contact for about 75 percent of the crashes will likely result in cost savings in addition to the aircraft and occupant costs.

"Advanced Helicopter Structural Design Investigation," USAAMRDL-TR-75-56A, March 1976. (Reference 13)

This study was undertaken to define advanced structural configurations for a Medium Range Utility Transport (MUT) helicopter. The latest analytical, material and fabrication technology was to be studied to satisfy requirements for structural efficiency, fail-safety, safety and producibility/cost. Risk/feasibility assessments were made to identify the areas of greatest payoff and risk, and to identify areas needing further research.

A baseline MUT was designed using "conventional" design techniques and metallic materials. This was used for comparison with the advanced design concepts investigated for the study.

Several advanced concepts were studied and layout drawings made to identify the major elements; structure, rotor system, drive system, flight controls and landing gear. Where relevant, several design and fabrication methods were studied and alternative materials assessed.

For each concept, including the baseline aircraft, weight performance and cost estimates were made. Risk/feasibility studies showed that the principal risks lie in the successful development of an all-composite hub, and in load transfer between the hub and transmission assembly.

It was concluded that:

- by using advanced structural techniques both the size and weight of the MUT helicopter can be reduced. Additionally, production quantities can be manufactured at less cost than a typical metallic helicopter designed for the same mission.

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[13] Hoffstedt, D.J., and Swatton, Sidney, ADVANCED HELICOPTER STRUCTURAL DESIGN INVESTIGATION, Volume I - Investigation of Advanced Structural Component Design Concepts, Boeing Vertol Company, USAAMRDL-TR-75-56A, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, 23604, March 1976, ADA 024662.

- the risk involved is not excessive in attempting to design and manufacture an advanced configuration helicopter.

- more weight savings could be realized than was claimed in the study, but insufficient evidence existed with respect to cost competitiveness and developmental data.

<u>"Investigation of Advanced Helicopter Structural Designs", USAAMRDL-TR-75-59A, May 1976</u>. (Reference 14)

This study was undertaken as a parallel contract to that of Reference 13.

A baseline design was used for comparison with potential advanced concepts in a similar manner as the parallel study.

For this study it was concluded that:

- the application of advanced concepts and materials to a MUT design can result in both cost and weight savings. This results in a greater payload capability for a MUT of the same gross weight as the baseline aircraft.

- concepts for airframe and landing gear are reasonably feasible and future research and development programs are recommended with medium risk.

- concepts investigated for the rotor system and control system are very feasible and represent a potentially low risk research and development program.

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[14] Rich, M.J., INVESTIGATION OF ADVANCED HELICOPTER STRUCTURAL DESIGNS, Volume I - Advanced Structural Component Design Concepts Study, Sikorsky Aircraft Div., United Technologies Corp., USAAMRDL TR-75-59A, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia 23604, May 1976, AD A0267246.

"Investigation of the Crash-Impact Characteristics of Advanced Airframe Structures," USARTL-TR-79-11, September 1979. (Reference 15)

The objectives of this study were to:

- survey literature and determine the current data pertaining to crash impact behavior of composite materials, analytical techniques used to design crashworthy airframes, and crashworthiness design criteria.

- assess current structural crash simulation techniques to determine their suitability for the analysis of composite structures.

- apply crashworthiness and airworthiness criteria to airframe structure constructed of composite materials to produce design concepts that better satisfy these criteria.

The results of the literature survey showed that composite structures are reasonably well understood for designs involving relatively low-level elastic response for both static and cyclical loading. However, insufficient attention has been directed towards the crashworthiness capabilities of composite structures. More data is required both to support analytical crash predictions and to support a vehicle design.

An assessment of computer crash simulations currently in use has shown the following with respect to advanced material applications:

- no satisfactory single code exists

- hybrid codes theoretically are incomplete

- finite element codes lack sufficient advanced materials capability.

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[15] Cronkhite, J.D., Haas, T.J., Berry, V.L., and Winters, R., INVESTIGATION OF THE CRASH-IMPACT CHARACTERISTICS OF ADVANCED AIRFRAME STRUCTURES, Bell Helicopter Textron, USARTL-TR-79-11, Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia 23604, September 1979, AD A075163.

It was recommended that for current crash simulations on advanced materials the following procedure be followed:

- use KRASH with applicable crush test data for preliminary parametric studies and gross evaluations

- for detailed design use DYCAST for analyzing orthotropic laminates. However, this code is still under development and has not been verified experimentally.

In the application of design criteria, MIL-STD-1290 (AV) (Reference 1) and the "Crash Survival Design Guide" (Reference 2), it was deduced that composite structures can be constructed which are capable of providing the desired levels of occupant protection for the defined 95th percentile potentially survivable accident. In the preliminary design phase care must be exercised in avoiding potentially hazardous failure modes which composites exhibit, such as low elongation fractures and splintering. At the same time, properties such as small deflections with high loading must be used to maintain the space envelope integrity required to preclude occupant crushing and/or to prevent exit jamming which may compromise timely egress.

Energy attenuation techniques are shown which employ underfloor collapsible beams and foam-filled tubes. The importance of joints and fitting attachments is also addressed. Concepts and computer simulation of selected structural configurations are presented for both metallic and composite designs.

The major conclusion of the study was that composites exhibit material properties and impact behavior which are not favorable at the structural element level. However, there is evidence that with inovative design crashworthy helicopter structures are feasible.

Recommendations were made for future programs with respect to materials, structural design, testing, simulation, and the coordination of potential programs undertaken by the Government and private industry.

"Crashworthy Landing Gear Study," USAAMRDL-TR-72-61, April 1973. (Reference 16)

This program's objectives were:

- to develop helicopter landing gear concepts and criteria to lessen the magnitude of crash forces transferred to the occupied areas of helicopters involved in survivable accidents without producing failure loading of the airframe.

- to design, fabricate, and test a skid-type crashworthy landing gear suitable for installation on the UH-1H helicopter.

A literature summary is given and landing gear design methodologies described in detail. Energy-absorbing concepts are investigated for both skid and wheel types of landing gear and the design for a UH-1H is optimized.

A computer program which solves the equations of motion of a three-dimensional analytical model of a helicopter landing gear system was described, and the program written using MIMIC was presented.

It was concluded that LOH, UH and CH helicopter classes could be equipped with landing gear which would limit the fuselage acceleration to 15G with a vertical impact velocity of 25 ft/sec.

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[16] Phillips, N. S., Carr, R. W., Scranton, R. S., CRASHWORTHY LANDING GEAR STUDY, Beta Industries, Inc.; USAAMRDL Technical Report 72-61, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, April 1973, AD 765489.

In addition, a UH type of skid gear could be produced for a 10-percent increase in structural weight to offer protection up to the 95th percentile vertical impact velocity while offering appreciable protection at realistic attitudes and proportionately reduced velocities.

It was recommended that in future research the landing gear be considered as a part of a total impact protection system and that design criteria be separated into the various helicopter classes such as LOH, UH and CH.

"Analytical Investigation of an Improved Helicopter Landing Gear Concept", USAAMRDL-TR-76-19, August 1976. (Reference 17)

The skid landing gear of the OH-6A helicopter was investigated and a redesign was proposed to offer a reduction in nose-down pitching moment during autorotation landings. This was necessitated by the excessive occurrence of tail boom impacts by the main rotor during an autorotation flare.

Modifications were made to incorporate a hydraulic damping system that interconnected the forward and rear landing gears. During the flare the aft gear impacts first and fluid transfer forces the forward gear towards the ground plane, thus limiting the nose-down pitching motion. The cross tubes of the gear were also extended to provide greater ground clearance and skid gear stroking capability.

In addition, the gear was assessed with respect to energy absorption when compared to the requirements of MIL-STD-1290 (AV) (Reference 1), and ground resonance, weight and life-cycle cost estimates were made.

Conclusions of the study were:

- more controllable autorotation landings are possible with the proposed configuration.

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[17] Logan, A.H., INVESTIGATION OF AN IMPROVED HELICOPTER LANDING GEAR CONCEPT, Hughes Helicopters, Division of Summa Corp., USAAMRDL-TR-76-19, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia 23604, August 1976, AD A029372.

- with the extended cross tubes the gear can withstand a vertical impact velocity of 19.5 ft/sec, a 5-ft/sec increase over the original design.

- the redundancy of the interconnection system and oleos increases helicopter reliability

- life-cycle cost analysis shows a cost savings of over two times the initial cost for a 15-year period.

It was recommended that interconnected wheel type landing gears be developed and tested for incorporation into the UTTAS and AAH types of aircraft.

Miscellaneous Literature

Other reports, documents, etc., were referred to for supporting data. These were concerned with seats and restraint systems, the YUH-61A Survivability/Vulnerability Status report, and maintenance manuals for various aircraft.

The design and testing of troop and gunner crashworthy seats and restraint systems are described in References 18 through 23. Concepts designed to MIL-STD-1290 (AV) are described and their development directed towards satisfying these requirements are delineated. These studies were funded

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[18] Reilly, M.J., CRASHWORTHY TROOP SEAT INVESTIGATION, Boeing Vertol Company, USAAMRDL-TR-74-93, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia 23604, December 1974, AD A007090.

[19] Reilly, M.J., CRASHWORTHY TROOP SEAT TESTING PROGRAM, Boeing Vertol Company, USAAMRDL-TR-77-13, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia 23604, November 1977, AD A048975.

[20] Reilly, M.J., CRASHWORTHY HELICOPTER GUNNER'S SEAT INVESTIGATION, Boeing Vertol Company, USAAMRDL-TR-74-98, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia 23604, January 1975, AD A005563.

[21] Reilly, M.J., CRASHWORTHY GUNNER SEAT TESTING PROGRAM, Boeing Vertol Company, USARTL-TR-78-7, Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia 23604, March 1978, AD A054970.

[22] Carr, R.W., and Desjardins, S.W., AIRCREW RESTRAINT SYSTEM - DESIGN CRITERIA EVALUATION, Dynamic Science Division, Ultrasystems, Inc., USAAMRDL-TR-75-2, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia 23604, February 1975. AD A009059.

[23] Carr, R.W., HELICOPTER TROOP/PASSENGER RESTRAINT SYSTEMS DESIGN CRITERIA EVALUATION, Dynamic Science Division, Ultrasystems, Inc., USAAMRDL-TR-75-2, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia 23604, June 1975, AD A012270.

as part of the Crashworthiness program of the U.S. Army Applied Technology Laboratory, Fort Eustis, Virginia.

Department of the Army Technical Manuals (References 24 through 28) were used to obtain data concerning structural details of the crashworthiness designs of the OH-6A, OH-58A, UH-1H, AH-1G and CH-47 A, B and C.

The survivability and vulnerability assessments of the YUH-61A are included in Reference 29. This gives crashworthiness assessments of the various elements of the design and an ADS-11 (Reference 30) evaluation for an aircraft designed to comply with crashworthiness requirements now included in MIL-STD-1290 (AV).

Summary Matrix of Literature Content

Figure 2 is a matrix of the primary contents of each of the literature referenced. This will assist the reader in the identification of specific reports for given subject matter.

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[24] DS AND GS MAINTENANCE REPAIR PARTS AND SPECIAL TOOLS LIST, OH-6A, TM55-1520-214-34P, Headquarters, Department of the Army, Washington, D.C., March 1973.

[25] AVIATION UNIT AND INTERMEDIATE MAINTENANCE REPAIR PARTS AND SPECIAL TOOLS LIST, OH-58A, TM55-1520-228-23P, Headquarters, Department of the Army, Washington, D.C., July 1977.

[26] DS AND GS AND DEPOT MAINTENANCE REPAIR PARTS AND SPECIAL TOOLS LIST, UH-1B, UH-1C, UH-1D, UH-1H, UH-1M, TM55-1520-210-34P-1, -2, -3 and -4, Headquarters, Department of the Army, Washington, D.C., April 1974.

[27] DS AND GS MAINTENANCE REPAIR PARTS AND SPECIAL TOOLS LIST, AH-1G, TM55-1520-221-34P-1 and -2, Headquarters, Department of the Army, Washington, D.C., December 1973.

[28] DS AND GS MAINTENANCE MANUAL CH-47B and -47C, TM55-1520-227-34-1, -2, -3, Headquarters, Department of the Army, Washington, D.C., July and August 1973.

[29] SURVIVABILITY/VULNERABILITY STATUS REPORT, YUH-61A, D179-10311-5, The Boeing Company, Vertol Division, Philadephia, Pennsylvania, 19142, March 1974.

[30] AERONAUTICAL DESIGN STANDARD, SURVIVABILITY/VULNERABILITY PROGRAM, ADS-11, U.S. Army Aviation Systems Command, St. Louis, Missouri, 63166, 7 September 1972.

INFORMATION / REFERENCE	DESIGN CRITERIA	CRASH PERFORMANCE OF TYPICAL HELICOPTERS	DESIGN FEATURES CONTRIBUTING TO CRASHWORTHINESS	COST ANALYSIS	DATA ON CRASH INJURY EFFECTS	STRUCTURAL FEATURES	TEST DATA
1 MIL-STD-1290 (AV)	●		●				
2 USARTL-TR-79-22	●	●	●		●	●	
3 USASC-TR-79-1		●	●	●	●	●	
4 USAAAVS-TR-78-4		●	●	●	●	●	
5 USAAAVS-TR-78-3		●	●	●	●	●	
6 CARNELL, B.L.		●	●	●		●	
7 BAINBRIDGE, R.E., ET AL		●	●			●	
8 HALEY, J.L. & HICKS, J.E.		●	●	●	●		
9 USAAAVS-TR-76-2		●	●	●	●		
10 USAAAVS-TR-77-2		●	●	●	●		
11 HICKS, J.E.		●	●	●	●		
12 MCDERMOTT, J.M., & VEGA, E.			●			●	
13 USAAMRDL-TR-75-56A			●	●		●	
14 USAAMRDL-TR-75-59A			●	●		●	
15 USARTL-TR-79-11		●	●			●	

Figure 2. Matrix of literature contents

REFERENCE \ INFORMATION	DESIGN CRITERIA	CRASH PERFORMANCE OF TYPICAL HELICOPTERS	DESIGN FEATURES CONTRIBUTING TO CRASHWORTHINESS	COST ANALYSIS	DATA ON CRASH INJURY EFFECTS	STRUCTURAL FEATURES	TEST DATA
16 USAAMRDL-TR-72-61			●			●	●
17 USAAMRDL-TR-76-19				●		●	
18 USAAMRDL-TR-74-93			●			●	
19 USAAMRDL-TR-77-13	●						●
20 USAAMRDL-TR-74-98			●			●	
21 USARTL-TR-78-7	●						●
22 USAAMRDL-TR-75-2			●			●	●
23 USAAMRDL-TR-75-10			●			●	●
24 TM55-1520-214-34P						●	
25 TM55-1520-228-23P						●	
26 TM55-1520-210-34P-1, -2 -3 & -4						●	
27 TM55-1520-221-34P-1 & -2						●	
28 TM55-1520-227-34-1, -2 & -3						●	
29 D179-10311-5			●			●	
30 ADS-11			●				

Figure 2. Continued

DATA SURVEY

This phase of the program was achieved in two stages and involved the collection and analysis of accident report information available from the United States Army Safety Center, Fort Rucker, Alabama.

Data Collection

Tabulated computer data for selected aircraft types were obtained from Fort Rucker for the OH-6A, OH-58A, UH-1H, AH-1G and CH-47. Time frames varied for each aircraft data sample but each was selected to provide adequate information for the analyses.

Time frames selected were:

OH-6A	1971-1973
OH-58A	1971-1974
UH-1H	1971-1976
AH-1G	1971-1975
CH-47	1971-1972

Tabulated computer data obtained, where available, were:

DA2397-1	Summary
DA2397-3	Narrative Summary
DA2397-6	In-flight or Terrain Impact Description and Crash Damage
DA2397-10	Personal/Protective Equipment, Restraint System and Seats
DA2397-15	Fire Data

These data were requested from Fort Rucker and reviewed at Boeing-Vertol for accidents involving major and substantial damage levels.

From the tabulated computer data package, furnished by Fort Rucker, a further review was made to isolate those accidents where injuries occurred. Minor, major and fatal injury categories were extracted for further review.

Summaries were made for each aircraft type to list each accident, the extent of damage and injuries, whether fire was involved and whether the accident was considered to be survivable.

This accident selection process resulted in 315 accidents being selected as a data base.

For detailed information concerning injuries, reference was made to actual accident reports on file at the U. S. Army Safety Center, Fort Rucker, Alabama. A total of 120 accidents were selected for this detailed review in order to obtain additional data about injury causal factors, impact conditions, structural failure modes, egress potential, terrain and photographic information. All of these accidents involved at least one injury.

Data Analysis

The objective of this phase of the program was to identify the accident conditions that prevailed where at least one injury occurred for the aircraft selected. Assessments were made as to whether each accident was survivable or non-survivable and whether fire was involved. Injury causal factors were compiled for each type of aircraft for use in the identification of potential design improvements to reduce crash casualties and to define injury distributions for use in cost analyses.

Tables 2 and 3 summarize tabulated computer accident data. The severity of the accidents, either survivable or nonsurvivable, is shown, as well as the types of injuries incurred, fatal (F), serious (S), or minor (M). Whether or not the aircraft was equipped with a crashworthy fuel system is also indicated. It should be noted that these data reflect absolute values for accidents and casualties and do not attempt to reflect injury causal factor distributions. One occupant may be responsible for several injury causal factors during an accident sequence and such data are included in the generation of Tables 4 and 5.

For the sample of accidents considered, many injury causal factors were identified either from accident reports directly or by reviewing injuries, aircraft damage and, where available, estimates of impact velocities and attitudes. These data were combined with the results of similar studies performed by the U.S. Army Safety Center for the OH-58A, CH-47 and AH-1 aircraft published in References 3, 4 and 5. An assessment of a crash hazard frequency rating was made for each causal factor using the same methodology as that used by the U.S. Army Safety Center in References 3, 4 and 5.

A summary of the frequency indices is contained in Table 4 for the injury causal factors identified; the definition of a frequency index being:

TABLE 2. SUMMARY OF SELECTED TABULATED COMPUTER RUN ACCIDENT DATA

ACCIDENT DATA / HELICOPTER TYPE	ACCIDENTS			TOTAL OCCUPANTS	INJURIES			PERCENT FATALITIES OF TOTAL OCCUPANTS		
					FATAL		SERIOUS			
	TOTAL	NON-SURVIVABLE	FIRE		TOTAL	FIRE ONLY		TOTAL ACC.	FOR NON-SURV.ACC.	FIRE ONLY
OH-6	68	7	16	171	28	8	42	16	8	5
OH-58	55	15	18	134	52	13	40	39	26	10
UH-1H	104	16	35	577	134	24	100	23	12	4
AH-1G	70	24	21	138	50	10	29	36	32	7
CH-47	18	6	13	93	35	8	14	38	33	9

NOTE: DATA SAMPLE FOR ACCIDENTS WHERE AT LEAST ONE OCCUPANT WAS INJURED

TABLE 3. SUMMARY OF ACCIDENT AND CASUALTY DATA FOR AIRCRAFT WITH CRASHWORTHY AND NONCRASHWORTHY FUEL SYSTEM INSTALLATIONS

				ACCIDENTS				CASUALTIES											
				WITHOUT FIRE		WITH FIRE		WITHOUT FIRE				WITH FIRE							
								SURVIVABLE ACCIDENTS			NON-SURV. ACC.	FIRE ASSOCIATED INJURIES				IMPACT ASSOCIATED INJURIES			
												SURVIVABLE ACCIDENTS			NON-SURV. ACC.	SURVIVABLE ACCIDENTS			NON-SURV. ACC.
AIRCRAFT TYPE	TOTAL ACCIDENTS	TOTAL OCCUPANTS	FUEL SYSTEM INSTL'N	SURV.	NON-SURV.	SURV.	NON-SURV.	F	S	M	F	F	S	M	F	F	S	M	F
[illegible]	[illegible]	[illegible]	NCW	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			CW			DATA	NOT	AVAILABLE	FOR	CRASHWORTHY	FUEL	SYSTEMS							
[illegible]	[illegible]	134	NCW	23	4		[illegible]	4	[illegible]	25	[illegible]	2	1		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			CW	[illegible]	1	3	2	3	12	[illegible]	2	[illegible]	[illegible]		[illegible]	4	[illegible]		4
[illegible]	[illegible]	[illegible]	NCW	[illegible]	1	[illegible]	[illegible]	31	[illegible]	[illegible]	[illegible]	4	[illegible]	[illegible]	13	[illegible]	[illegible]	[illegible]	[illegible]
			CW	[illegible]	[illegible]	11	[illegible]	[illegible]	21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AH-1[illegible]	[illegible]	[illegible]	NCW	[illegible]	[illegible]	3	14	3	21	35	12	[illegible]	1	[illegible]	[illegible]	2	2	1	[illegible]
			CW	4	2	3	1	[illegible]	4	2	4	[illegible]	1	[illegible]	[illegible]	2	[illegible]		
[illegible]	[illegible]	[illegible]	NCW	3	2	[illegible]	4	[illegible]	1	[illegible]	[illegible]	2	[illegible]	[illegible]	[illegible]	4	[illegible]	14	[illegible]
			CW			INSUFFICIENT		DATA	AVAILABLE		FOR	CRASHWORTHY	FUEL	SYSTEMS					

NOTE: Each casualty is allocated to the injury category which represents the primary injury cause. Multiple injuries are not counted as multiple casualties.

Injury Categories:
F Fatal
S Serious
M Minor

TABLE 4. INJURY CAUSAL FACTORS

Injury Causal Factor / Type of Helicopter	OH-6	OH-58	AH-1G	UH-1H	CH-47
Structural collapse into occupied space - crushing	D	B	B	B	B
Excessive vertical "G" load	B	B	B	B	B
Impact with internal structure; seat/restraint failure; flailing	B	C	B	B	E
Rotor blade penetration of occupied space	E	C	B	C	E
Penetration of occupied space by external object(s)	D	B	E	E	E
Seat collapse	C	C	C	D	B
Seat armor displacement	E	D	E	E	E
Restraint system failure; webbing, hardware, inertia reel	E	D	E	E	E
No seat provided or seat inadequate to perform task(s)	E	E	E	D	A
Seat/restraint not used when provided	E	E	E	D	A

TABLE 4. CONTINUED

Injury Causal Factor \ Type of Helicopter	OH-6	OH-58	AH-1G	UH-1H	CH-47
Inadequate cargo restraint or failure to use restraint	E	E	E	D	B
Transmission/hydraulic oil spillage; occupant burns or fire	E	E	E	B	B
Fire due to fuel system failure on impact	B	D	C	C	B
Drowning due to inadequate egress potential	E	E	E	E	E
Displacement of armored vest during impact	B	E	E	D	E
Displacement of helmet and subsequent head impact	D	D	E	E	E
Walked into rotating blade(s) after exiting	C	E	E	E	E
Multiple injuries in non-survivable impact	C	B	A	A	A
Ejection from helicopter and subsequent crushing	E	D	E	E	D

Crash Hazard Frequency Ranking

Frequency Index	Descriptive Nomenclature	Mathematical Definition
A	Frequent	$0.5 < f^*$
B	Reasonably probable	$0.1 < f < 0.5$
C	Occasional	$0.05 < f < 0.1$
D	Remote	$0.01 < f < 0.05$
E	Improbable	$f < 0.01$

*f is defined as the relative frequency of injury occurrence and is calculated as

$$f = \frac{\text{Frequency of occurrence of resulting injuries}}{\text{Number of accidents studied}}$$

Table 4 indicates areas of potential improvement for each aircraft with respect to occupant injuries and these data were used in Phase II to upgrade the crashworthiness of each aircraft by improving areas identified as deficient.

From crash impact data contained in the DA2397-4 forms and from assessments of photographic records, impact velocities were estimated where sufficient information was available. These data in conjunction with injury data and data furnished in References 3, 4 and 5 were used to obtain indications of overall aircraft performance in a crash situation. Figure 3 provides velocity envelopes for selected aircraft for potentially survivable impact conditions. This was obtained by selecting accidents where at least one occupant survived and by drawing a curve which encompassed approximately 95 percent of these data points. It must be noted that these are absolute values of vertical and longitudinal velocity and not velocity changes for the primary impact pulse. For comparison, the primary impact pulse velocity change envelope from TR-71-22 is shown.

In the case of vertical impact velocity, the absolute velocity and primary pulse velocity change are substantially the same value. Three of the aircraft studied had sufficient data to allow an assessment of injury potential as a function of vertical impact velocity. Figure 4 shows these relationships and indicates that the OH-58A, AH-1G and CH-47 aircraft do not possess the crash resistance required by MIL-STD-1290 (AV). Such a result is understandable since all of these aircraft were designed before the evolution of MIL-STD-1290 (AV) when crashworthiness requirements

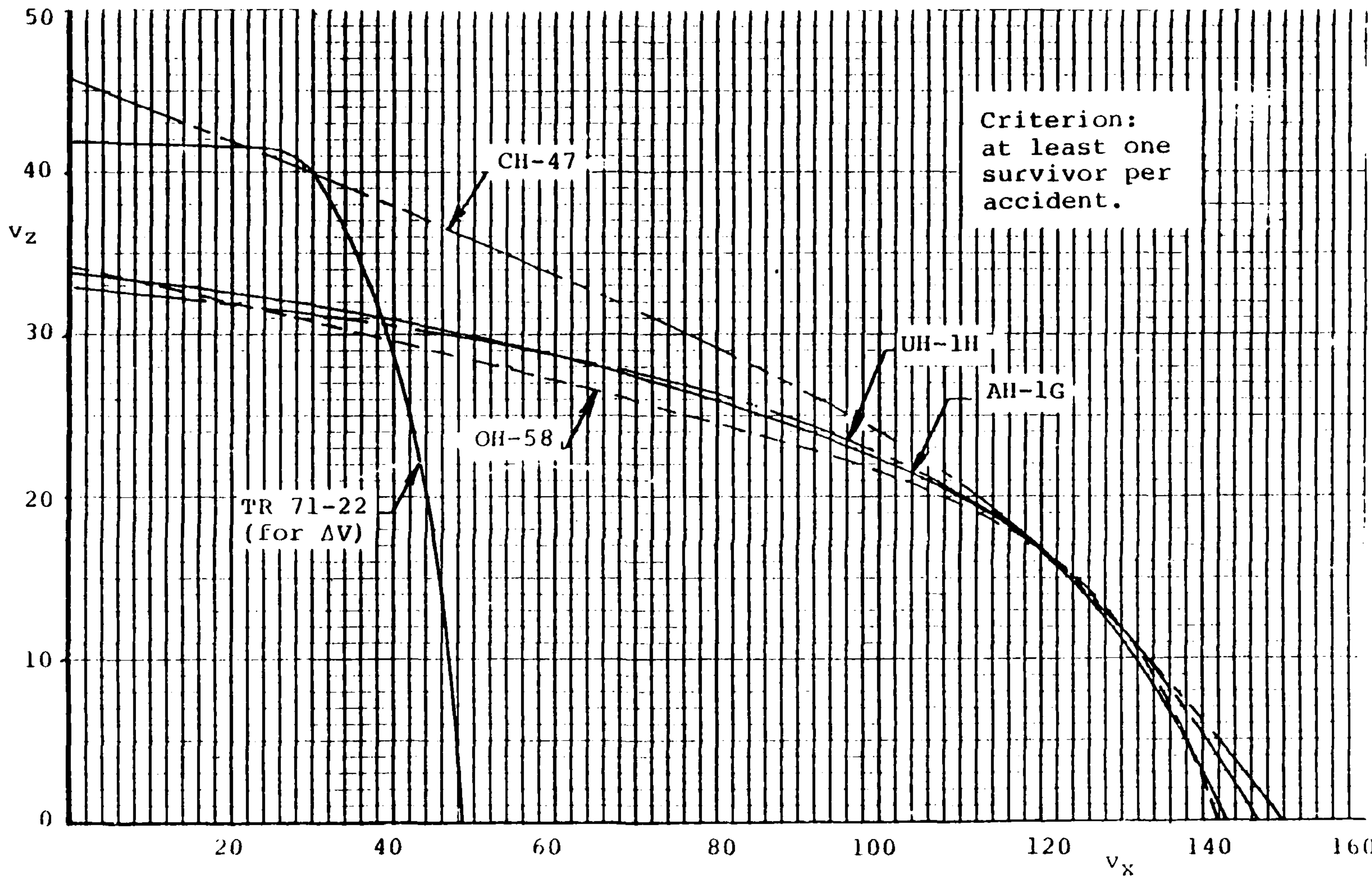

Figure 3. Potentially survivable impact velocity envelopes

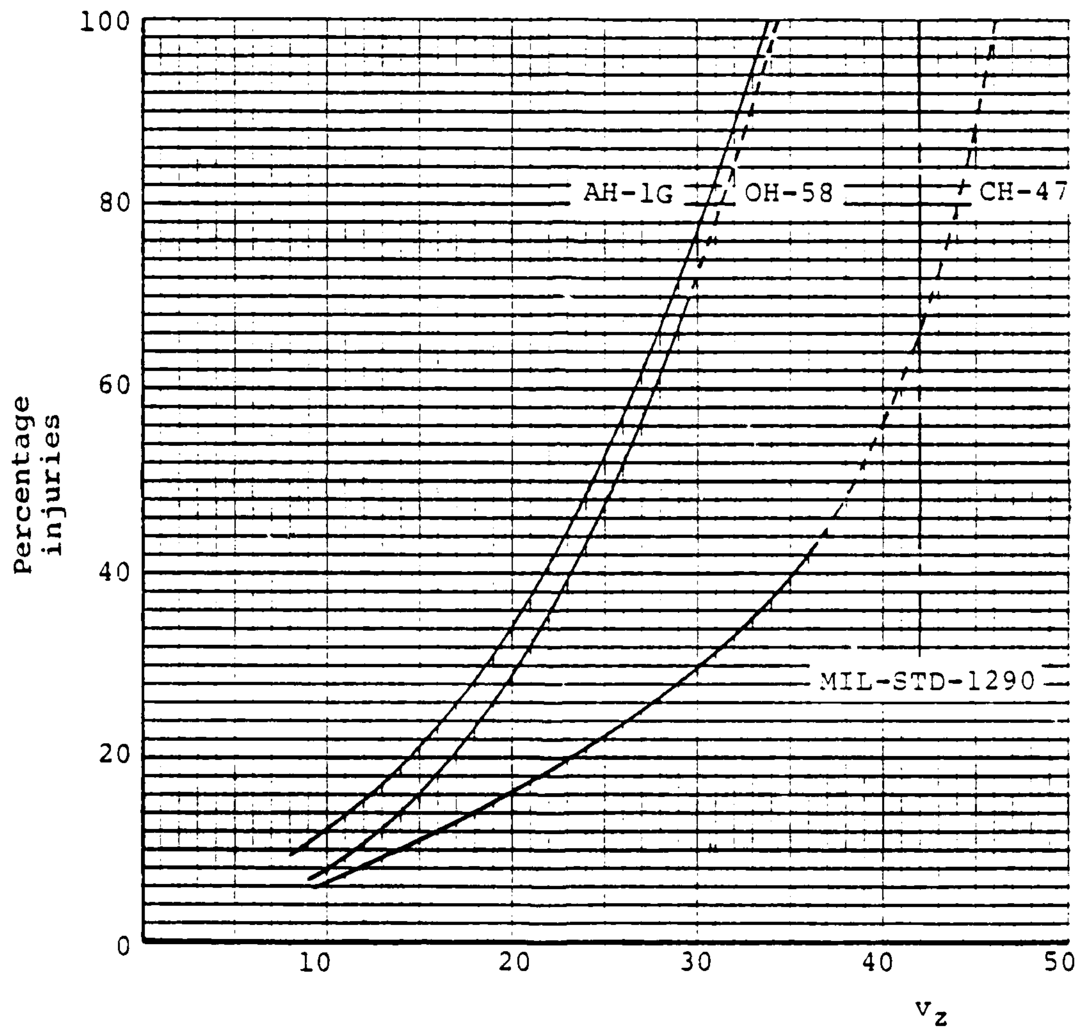

Figure 4. Injury potential as functions of vertical impact velocity

were much less stringent. These curves were used during Phase II of this program where potential improvements were identified and the weight and cost deltas estimated for the incorporation of such improvements.

Operational Problems

During the data review it was apparent that an improvement in accident and casualty rates and their associated costs could be achieved. Certain operational problem areas could be improved or the aircraft designed to minimize the effects of a crash or to prevent the occurrence of a crash.

Operational problems which contribute to the eventual precipitation of accidents can be identified. Design improvements and/or operator procedures can be better defined and implemented to alleviate some of these problems and to assist in minimizing the number of accidents that occur. This in turn results in better accident statistics and cost savings over the fleet life of a particular aircraft. Table 5 summarizes the prevalent operational problems noted during this study and lists potential improvements to minimize the occurrence of accidents due to such problems.

TABLE 5. PREVALENT OPERATIONAL PROBLEMS AND POTENTIAL IMPROVEMENTS

PROBLEM	POTENTIAL IMPROVEMENTS	REMARKS
1 Flight into: ● IMC with disorientation ● Wires ● Trees ● Terrain	● Operating procedures to be well defined and implemented ● PVNS for night and IMC vision enhancement ● Wire cutters and deflectors	● must not be over-ruled by "must do" attitudes ● PNVS & wire cutters under development
2 Landing on: ● Uneven terrain ● Excessive slope ● External Cargo	● Crew visibility via improved transparency location ● Procedures for review of landing site by crew and/or ground operators	● A more disciplined crew attitude needed to minimize such occurrences
3 Taxiing into or blade strikes of: ● Buildings, revetments ● Trees ● Other aircraft ● Sloped terrain	● Crew visibility via improved transparency location	● Same as 2

TABLE 5. CONTINUED

PROBLEM	POTENTIAL IMPROVEMENTS	REMARKS
4 Recovery to landing after: ● Power loss ● Tailward wind velocity and marginal power available ● Tail rotor loss	● Twin-engine installation with adequate single engine performance	● Rapid crew recognition and action needed (see 5)
5 Tail rotor failure mode identification: ● Loss of power ● Loss of control ● Control failure to full thrust position	● Cockpit information to tell crew type of failure that occurred	● Current problem compounded by need for correct and rapid crew response with differing control inputs depending on failure mode

PARAMETRIC SENSITIVITY ANALYSES

The objective of the Parametric Sensitivity Analyses was to develop trend data for crashworthiness cost and weight as a function of helicopter weight and level of crashworthiness achieved. The purpose of this trend data was the identification of crashworthiness cost and weight drivers to assist in determining R&D efforts necessary to reduce the penalties associated with incorporating crashworthiness into future helicopter designs.

Trend data were developed to reflect parametric relationships of six specific crashworthiness features when applied to helicopter systems covering a gross weight spectrum from 2,400 to 50,000 pounds. Sensitivity of these parametric relationships to airframe material, number of engines and mission type were also defined. The analyses process is shown in block diagram format in Figure 5.

Seven aircraft were selected for study during this phase of the program. They were the five investigated during phase 1, OH-6A, OH-58A, UH-1H, AH-1G and CH-47, and two additional aircraft, the YUH-61A and CH-47D. The rationale for the selection of these aircraft was based on the adequacy of data obtained for the initial five aircraft, the availability of existing analyses for the other two, and the need to have sufficient aircraft to cover the gross weight spectrum from 5000 to 50,000 pounds. It should be noted that all these aircraft were not designed to MIL-STD-1290 although the YUH-61A was designed to the requirements of TR71-22.

CRASHWORTHINESS SCORING METHODOLOGY

The key to the sensitivity analyses process was the establishment of a "scoring" technique which allowed comparison of the effects of variations in the parametric values for the six evaluated crashworthiness features. The "scoring" technique employed a modified version of the ADS-11A (Reference 30) methodology. The relative hazard potential relationships were retained but numerical values were regrouped into the six crashworthiness features under evaluation in this study as shown in Table 6. The optimum number shown for each feature and for the aircraft system were defined as a 100 percent MIL-STD-1290 rating for the purposes of this study.

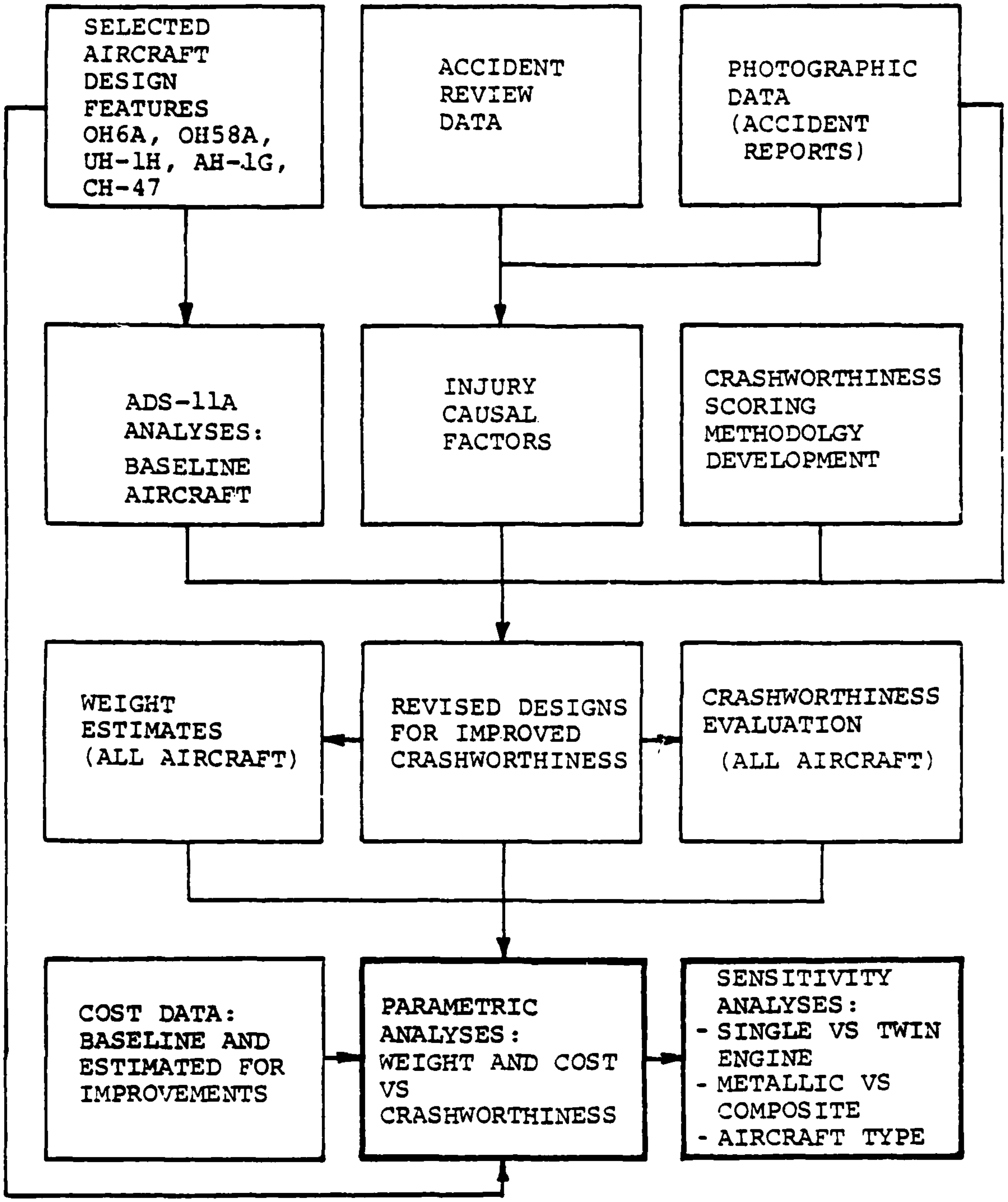

Figure 5. Process for defining weight ,cost and crashworthiness levels for baseline and improved aircraft

TABLE 6. SYSTEM SCORING VALUES

Crashworthiness Feature	Optimum Number
Crew Seat System	125
Troop/Gunner Seat System	125
Landing Gear	25
Postcrash Fire Prevention	255
Emergency Egress	60
Airframe Crashworthiness	130
Aircraft System	720

Tables 7 through 12 define the assessment methodology employed to rate each crashworthiness feature. As noted above, the total optimum number for each feature represents a 100 percent MIL-STD-1290 design.

It must be noted that these scores represent the individual assessments for the specific crashworthiness parameters. As such they are useful for identifying specific areas of a design that need improvement to upgrade them to levels consistent with the desired overall crashworthiness level, the maximum achievable being 100 percent of MIL-STD-1290.

The various crashworthiness parameters are integral parts of the overall design and are dependent variables. The rating for a total aircraft system, expressed as a percentage of MIL-STD-1290, must consist of a balanced mix of scores for the parameters; ideally, each parameter should have a score of 80 percent for an overall aircraft rating of 80 percent.

In subsequent analyses where improved levels of crashworthiness have been defined for implementation into existing designs, efforts have been made to equalize parameter values where possible. The overall percentage score that resulted was then used to express weight and cost variations for the crashworthiness parameters as functions of a MIL-STD-1290 rating for the total aircraft system.

TABLE 7. CREW SEAT SYSTEM SCORING VALUES

Feature	Optimum Number		Assessment Methodology
Vertical E/A Capability	30		% E/A capability when compared to seat designed to MIL-S-58095
Restraint Webbing Geometry and Strength	25		
• Lapbelt		15	Rate each on basis of % strength
• Shoulder Harness		10	
Seat Longitudinal Strength	10		% static G capability vs MIL-S-58095
Seat Lateral Strength	10		% static G capability vs MIL-S-58095
Seat Vertical Strength	10		% static G capability vs MIL-S-58095
Castings	10		Either/or
Shoulder Strap Pull-Off Angle	5		Rate on how close to desired angle
Lap Belt Angle to Seat Cushion	5		Rate on how close to desired angle
Lap Belt Tiedown Strap	5		Either/or
Inertia Real Type	5		Either/or
Depth of Structure Between Floor and Belly	10		% of desired two feet as modified by shape and crushability
TOTAL	125		

TABLE 8. TROOP/GUNNER SEAT SYSTEM SCORING VALUES

Feature	Optimum Number		Assessment Methodology
Vertical E/A Capability	30		% E/A capability based on controlled vertical stroking distance provided
Restraint Webbing and Geometry	20		Rate on basis of % strength
• Lapbelt		10	
• Shoulder Harness		10	
Seat Longitudinal Strength	10		Rate on % static G capability compared
Seat Lateral Strength	10		to MIL-STD-1290
Seat Vertical Strength	10		
Castings	10		Either/or
Shoulder Strap Pull-Off Angle	5		Rate on how close to desired angle
Lap Belt Angle	10		Rate on how close to desired angle
Lap Belt Tiedown Strap	5		Either/or
Depth of Structure	10		% of desired two feet as modified by shape and crushability
TOTAL	125		

TABLE 9. LANDING GEAR SYSTEM SCORING VALUES

Feature	Optimum Number	Assessment Methodology
Location	5	Rate based on damage potential as the gear might be displaced in a crash. Particular hazards are relative location to fuel and occupants.
Vertical Force Attenuation	20	Assess attenuation capability without fuselage contact and rate as follows: $\left[\frac{\text{Vel Capability}}{(\text{20 fps desired})}\right]^2 [20] = \text{Rating}$
TOTAL	25	

TABLE 10. POSTCRASH FIRE PREVENTION SCORING VALUES

Feature	Optimum Number	Assessment Methodology
Oil & Fuel Containment	20	
Engine Location & Tie Down	10	
Battery Locating & Tie Down	6	
Wire Routing	6	Rate in accordance with ADS11A guidelines for all systems
Boost Pump	2	
Inverter Location	3	
Generator Location	3	
Lights	3	
Antenna	2	
	55	
Fuel Containment	60	1. These 200 pts are rated dependent on type CWFS installed.
Flammable Fuel Lines	30	
Firewall	9	
Fuel Flow Interrupters	9	2. If non-crashworthy, the rating will be per ADS-11A guidelines.
Induction & Exhaust Flame	30	
Hot Metals	30	
Engine Location	5	3. If crashworthy, all these ADS-11A ratings will be upgraded to account for flammable fluid control provided by a CWFS. Crashworthiness levels will be assessed based on drop height criteria specified in CWFS designs.
Battery Location	6	
Wire Routing	6	
Boost Pump	5	
Inverter	3	
Generator	3	
Lights	2	
Antenna	2	
	200	
TOTAL	255	

TABLE 11. AIRFRAME SCORING VALUES

Feature	Optimum Number	Assessment Methodology
Crushing of Occupied Troop Areas (Longitudinal)	15	Rate based on distance and structure available to react loads. 100% rating for 40 fps ΔV capability. Scale down on ΔV^2 ratio for lower capability.
Plowing Tendency	10	Rate based on evalution of underfloor structural arrangement
Resistance to Longitudinal Impact Loads	10	Rate based on evaluation of structural arrangement
Resistance to Vertical Impact Loads	20	Rated based on vertical "G" capability vs 20 G desired on a linear basis
Resistance to Lateral and Roll-over Impact Loads	20	Rate based on lateral "G" capability vs 20 G desired on a linear basis
Effect of Blade Strike	20	Rated based on protective shell available and type blades used
Effect of Fuselage Separation	5	Rate based on potential hazards associated with most likely fuselage separation points
Proximity of Cockpit Controls and Other Structure	10	Rate based on proximity of controls to occupants and potential occupant motions due to seat and structure deflections and deformations

TABLE 11. (Continued)

Feature	Optimum Number	Assessment Methodology
Retention of Interior Equipment	10	Rate based on structural provisions for tiedown strength of mass items
Rudder Pedal Area	5	Rate based on structural strength and layout in vicinity of pedals
Absence of Injurious Objects in Cabin	5	Rate based on structural sharp corners and protrusions adjacent to occupants
TOTAL	130	

TABLE 12. EGRESS SCORING VALUES

Feature	Optimum Number	Assessment Methodology
Ease & Reliability of Exit Operation	15	Rate based on type jettison system, jam potential and distribution relative to occupants
Ratio of Usable Exits to Occupants	15	One exit per 10 occupants rates full score. Ratio down on square basis for designs that exceed this value, i.e., for one exit per 20 occupants the score would be 4.
Identification of Exits	10	Either/or
Availability of Exits in Rolled Aircraft	10	One exit per 10 occupants rates full score. Ratio down on linear basis for designs exceeding this value.
Emergency Lighting	10	Either/or

CRASHWORTHINESS ASSESSMENTS

Using a combination of aircraft design data, crash data, and estimates of potential improvements, each aircraft was assessed using the quantitative but subjective technique defined above.

All elements of the design where crashworthiness requirements are concerned must be optimized to offer the maximum level of protection to all occupants. These requirements are defined in MIL-STD-1290 (AV) (Reference 1) and TR 79-22 (Reference 2) which is an updated version of TR 71-22 (Reference 31). Table 13 shows the salient crashworthiness requirements defined in both MIL-STD-1290(AV) and TR-71-22. The objective of a good crashworthy design is to meet as closely as possible the requirements specified when considered in conjunction with design restraints with respect to performance, mission, and transportability.

There are six basic crashworthiness elements to be considered in these analyses, and they are discussed with respect to their criticalities and potential improvement.

Crew Seat Systems

The environment in the cockpit with respect to acceleration is often more severe than in the cabin due to the proximity of the seats to the impacting structure if a longitudinal velocity component exists with respect to the aircraft axes.

Seats must be retained by attaching structure, restraint systems designed to minimize the motions of occupants, and, where necessary, the seats should stroke in order to minimize occupant 'G' levels to survivable levels.

Stroking of seats is needed if the landing gear-structure combination cannot reduce the occupant 'G' levels to survivable limits for the 5th through 95th percentile occupants.

Seat structure, the restraint system, and all attachments must be designed to criteria that preclude ultimate failure

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[31] CRASH SURVIVAL DESIGN GUIDE, Dynamic Science, A Division of Marshall Industries., USAAMRDL-TR-71-22, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia 23604, October 1971, AD733358.

TABLE 13. SPECIFIED STRUCTURAL CRASHWORTHINESS REQUIREMENTS

Impact direction	Impacted surface	Velocity differential (ft/sec)	Vehicle attitude limits	Percentage volume reduction	Other requirements	Data source
Longitudinal	Rigid	20		No hazard to pilot/copilot	Does not impede postcrash egress	Volume II
		40		15 max. length reduction for pass./troop compartment	Inward buckling of side walls should not pose hazards	MIL-STD-1290 Volume II
Lateral	Rigid	30	±20° Yaw	[illegible] max. width reduction	Lateral collapse of occupied areas not hazardous. No entrapment of limbs.	MIL-STD-1290 Volume II
Vertical	Rigid	42	+25°/-15° Pitch ±20° Roll	15 max. height red. in pass./troop compartment	G loads not injurious to occupants	MIL-STD-1290 Volume II
Resultant	Rigid	50	Combination	As above for various components	Max. velocity changes: long. = 50 ft/sec, vert. = 42 ft/sec, lat. = 30 ft/sec[a], 25 ft/sec[b]	MIL-STD-1290 Volume II
Rollover	Earth	-	90° sideward or 180° inverted or any intermediate angle	Minimal (doors, hatches, etc. assumed to be non-load carrying)	Forward fuselage buried to depth of [illegible] in. (inverted or on side). Load uniformly distributed over forward 25% of occupied fuselage length. Can sustain 4 G without injury to seated and restrained occupants. All loading directions between normal and parallel to skin to be considered.	MIL-STD-1290
Rollover (post-impact)	Rigid		Two 360° rolls (max.)	15 max. volume reduction (5% desired)		MIL-STD-1290
Earth plowing & scooping (longitudinal)	Earth	-	-	-	Preclude plowing when forward 25% of fuselage has uniformly applied vertical load of 10 G and rearward load of 4 G or the ditching loads of MIL-A-008865A, whichever is the greatest.	MIL-STD-1290
Landing gear	Rigid	20	±10° Roll ±10° Pitch	None. Plastic deformation of gear and mounting system allowable	Aircraft deceleration at normal G.W. for impact with no fuselage to ground contact. All other A/C structural parts, except blades, should be flightworthy following crash.	MIL-STD-1290
Landing gear	Sod	100 long.[c] 14 vert.	-5° Pitch ±10° Roll ±20° Yaw	15 max. volume reduction (5% desired)	No rollover, or if rollover occurs, two 360° rolls without fuselage crushing	MIL-STD-1290 Volume II

a) Light fixed-wing aircraft, attack and cargo helicopters.
b) Other helicopters.
c) Velocity at impact, not differential.

(FROM REFERENCE 2)

NOTE: DATA SOURCE VOLUME II REFERS TO REFERENCE 2.

during a survivable crash sequence. If this is not done a seat or restraint system that fails can result in severe injury to the occupant. Figure 6 shows a typical example of a poorly designed backup structure. It is apparent that the attachments and structural elements of the seat are sound but the backup structure has failed completely.

In subsequent analyses the seat performance will be assessed, keeping the above factors in mind and when installing stroking seats into improved design configurations.

Troop/Gunner Seat Systems

Although these seats are simpler in design than crew seats, primarily due to a non-adjustable fixed configuration being used, the basic requirements remain the same with respect to retention and restraint.

Past restraint system designs have often used a simple lap belt. This is completely inadequate to restrain an occupant; a full shoulder harness-lap belt combination should be used.

In medium and heavy lift aircraft, troop seats are often arranged along the sides facing in a lateral direction. Although this may be expedient from the operational viewpoint, it results in potentially less effective occupant protection.

Variable attentuators are not considered for troop seat installations since this would not be compatible with rapid troop movements.

A major concern when stroking seats are installed is that nothing should be stowed underneath to preclude full stroking; this is a matter of training.

Landing Gear

Landing gear designs vary considerably from the simple skid types to the ones with a 42-ft/sec impact capability without ultimate failure; this range can also be equated to greater weight and higher cost.

A gear designed to preclude ground contact of the underfuselage at 20 ft/sec impact velocity and no ultimate failure at 42 ft/sec can offer appreciable protection in a large proportion of all crashes.

Figure 6. Poorly designed seat backup structure

As with seats, the integrity of the gear, attachments and backup structure is critical and the installation must consider this. Structural integrity is important since failure can result in the gear becoming a mechanism with no energy attenuation capability but with the capability to penetrate the cabin area or other critical locations such as the fuel cell.

If skid gear is used, materials should be selected which have good yield characteristics. This will minimize the generation of potentially damaging sharp ends which may penetrate the cabin in subsequent motions of the aircraft. Figures 7 and 8 show examples of ductile and fractured skid gear respectively.

Postcrash Fire Prevention

The basic requirement to minimize the probability of a postcrash fire is to contain potentially flammable liquids, vapors and gases, minimize ignition source potential, and segregate all potential ignition sources and flammable agents that may leak.

Potential combustants are fuel, hydraulic fluids, lubricating oils, and cargo. Ignition sources may result from hot surfaces, electrical sparking and abrasion sparking.

The problems involved in a total aircraft system are quite extensive with the primary effort being directed toward fuel containment.

Incorporation of self-sealing breakaway fittings, impact-resistant fuel cells, electrical wiring harness loops (to allow for structural deformation), together with the segregation of potential ignition sources and leakage areas all contribute to the minimization of fire potential.

From the total viewpoint, it is considered that fuel cells must be designed to retain their integrity during any survivable crash sequence. Since a small fire can erupt into a major conflagration very rapidly if sufficient leakage of combustibles occurs, only minor leakage/seepage can be tolerated. Fire progression rate must be compatible with emergency egress of all occupants, be they active or require assistance. For this reason it is considered that fire protection is a "yes" or "no" type of decision with respect to the fuel cell. It is either designed to survive a given impact condition or its usefulness must remain questionable. Parameters that can influence the overall crashworthiness

Figure 7. Ductile deformation of skid gear

Figure 8. Failed skid gear members

assessment of the aircraft, such as location of electrical equipment, engine location, etc., can be addressed by optimizing their locations relative to areas where combustible materials may be released. Basically, improved ADS-11 scores, or percentages of MIL-STD-1290 (AV) requirements, can be achieved without significant increases in weight or cost but by judicious allocation of systems within the aircraft. Compromises that must be made due to overriding design requirements will result in ADS-11 scores which are less than optimum with respect to fire potential.

Emergency Egress

The major requirement for emergency egress is to provide all occupants adequate opportunity to safely exit from the aircraft in any postcrash attitude, on land or in the water, and when visibility is good or bad.

MIL-STD-1290 specifies the numbers of exits required, markings, lighting, etc., and it was assumed for this study that exit integrity can be achieved by using existing structural members. Frame members, longitudinal beams and floor members designed to react large mass item and impact loads are used to act as frameworks for doors and emergency exits. This provides a frame which precludes or minimizes jamming of exits and in conjunction with an easily operated release mechanism satisfies the military crashworthiness requirements.

Thus by judicious structural arrangement the implementation of satisfactory emergency egress capability will not result in increased weight or cost, or any deltas being assigned to the basic body structure.

Airframe Crashworthiness

The airframe has to provide a safe enclosed envelope for occupants with respect to mass retention and penetration. At the same time, a survivable "G" environment is needed which requires energy attenuation by the landing gear, structure and seats acting in series for vertical impacts. For longitudinal impacts the structure, seats and restraint systems are critical together with space envelopes, to allow extremity flailing without damaging impacts.

Distribution of structural elements must be optimized to provide support for mass items, landing gear attachments and occupants; to attenuate energy for impacts; to provide rollover and blade impact protection; to protect fuel cells and expensive onboard equipment; and to ensure that emergency exits remain functional after the crash sequence. It is apparent that a well-designed airframe with correctly installed seat systems will offer excellent protection to occupants during a crash sequence from "G" effects and mass penetration. In addition it is required that adequate space be provided to minimize injuries due to penetration, the generation of damaging structural elements and impact with the interior of the aircraft.

Typical examples of the results of not providing such occupant protection are shown in Figures 9 through 16. Figure 11 emphasizes the problems associated with mass items entering occupied space, and Figures 11 through 16 show some effects of penetration by blades, transmissions and failed structural elements.

Estimates of weight and cost to provide optimum protection are assessed for the aircraft considered. As noted previously some of the benefits of improving the structural design result in better protection for fuel, avionics and other aircraft systems and also good emergency egress.

Crashworthiness Assessments for Selected and Improved Aircraft

A total of seven aircraft were selected for study: OH-6A, OH-58A, UH-1H, AH-1G, YUH-61A, CH-47C and CH-47D. These aircraft, as designed, are referred to as the baseline aircraft and each was given a crashworthiness rating using the method defined in Reference 30.

Assessments were made based on published structural information and the failure modes and injury causal factors determined during the accident survey. Improvements were identified and a new crashworthiness score was computed for each design.

The ADS-11A methodology was used while keeping in mind the requirements specified in MIL-STD-1290 (AV), since the ultimate objective of this program is to express data as functions of the level of MIL-STD-1290 included in a design. Where necessary, modifications were made in the interpretation of ADS-11A to accommodate specific design peculiarities. For example, in the AH-1G there is no troop cabin but the crew sit in tandem. Since the forward crew member

Figure 9. Major structural failures of occupant space envelope

Figure 10. Structural failure of bulkhead aft of passenger seats

Figure 11. Intrusion of transmission assembly into cabin area

Figure 12. Penetration of occupied space

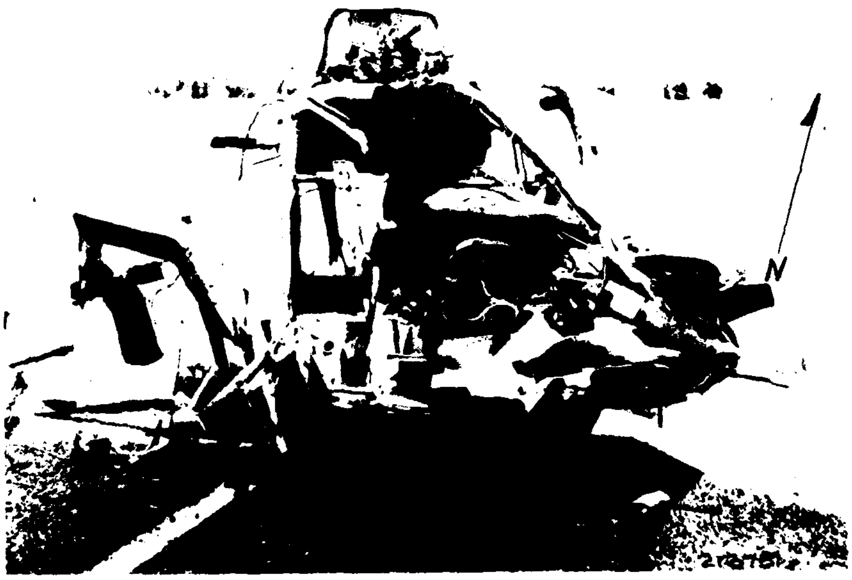

Figure 13. Penetration of occupied space

Figure 14. Penetration of occupied space by main rotor blade

Figure 15. Penetration of occupied space by rotor assembly

Figure 16. Intrusion of failed structural members into occupied space

is in a more vulnerable location it was assumed that the forward one was the crew and the aft one the cabin occupants, or troops.

Table 14 gives the ADS-11A scores for each of the seven selected aircraft and Table 15 lists the improvements that accrue when all areas are improved as much as possible. Individual ADS-11A analyses for the baseline aircraft are included in Appendices A through F of this report.

In all cases it was assumed that a crashworthy fuel system installation was used.

Figures 17 through 22 present diagrams for the six crashworthiness parameters defined in the scoring methodology section showing the differences between the baseline and improved aircraft to allow comparisons with the "perfect", 100 percent MIL-STD-1290 vehicle. Improvements are identified for each aircraft and presented with each figure. The improved scores for relevant crashworthiness features are given in Table 15.

Figure 23 shows the base and improved aircraft crashworthiness levels in block diagram format to provide an insight into the levels that can be achieved.

It must be remembered that the improved designs were based on the configurations of the existing aircraft. This resulted in certain compromises as a result of layout, systems integration and restrictions due to the influence of operational requirements.

A typical example of the approach used to improve the structural capabilities of each aircraft is shown in Figure 24. This shows plan and side elevation views of the UH-1H aircraft and identifies basic structural members incorporated in the base design and the areas where structure was improved or added for the improved configuration. Additional features included are improved landing gear, structural attachments for crashworthy seat installations, increased underfloor structure for energy absorption, and a canted frame member to minimize the probability of nose plowing.

Casualty Data for Existing and Improved Aircraft

Cost analyses require data involving injury distributions and causal factors.

TABLE 14. BASIC CRASHWORTHINESS COMPARISON SUMMARY

Basic Factor	Optimum Number ADS-11	YUH-61A	CH-47C	CH-47D	UH-1H	AH-1G	OH-58	OH-6A
Crew retention system	125	118	52	52	50	53	58	47
Troop retention system	125	123	44	44	40	59	35	36
Postcrash fire potential	255	224	172	210	200	211	203	196
Basic airframe crashworthiness	100	100	74	89	37	43	40	59
Landing gear	25	23	10	10	10	7	8	13
Evacuation	60	45	51	51	45	55	50	60
Injurious environment	30	25	24	24	17	27	19	23
TOTAL	720	658	427	480	399	455	413	434

TABLE 15. IMPROVED CRASHWORTHINESS COMPARISON SUMMARY

Basic Factor	Optimum Number ADS-11	YUH-61A	CH-47C	CH-47D	UH-1H	AH-1G	OH-58	OH-6A
Crew retention system	125	118	115	115	90	107	97	100
Troop retention system	125	123	115	115	111	112	95	96
Postcrash fire potential	255	224	172	210	200	211	203	196
Basic airframe crashworthiness	100	100	82	97	50	50	53	72
Landing gear	25	23	23	23	23	22	23	23
Evacuation	60	45	51	51	45	55	50	60
Injurious environment	30	25	24	24	17	25	19	23
TOTAL	720	658	582	635	536	582	540	570

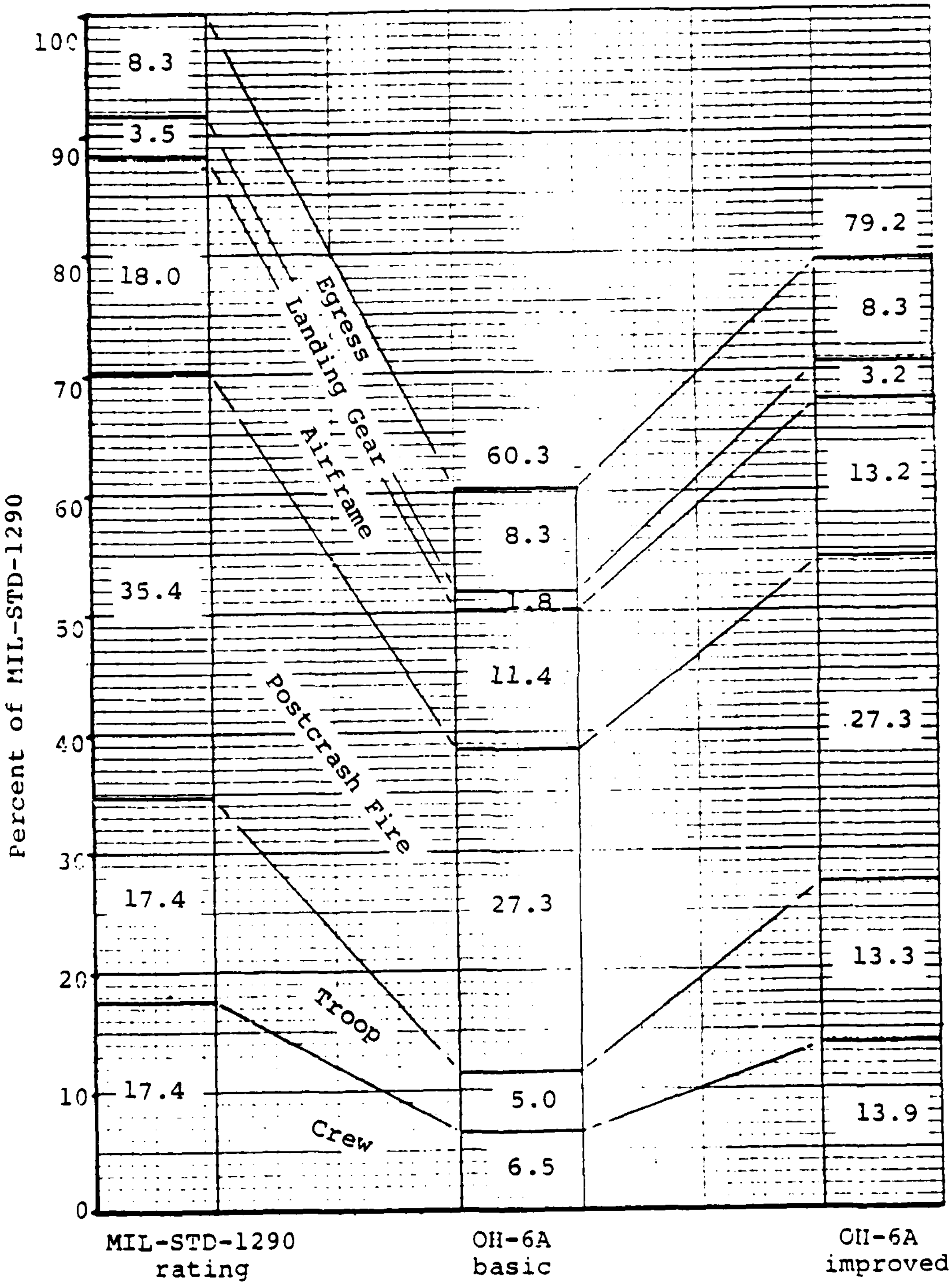

Figure 17. OH-6A rating

OH-6A IMPROVEMENTS

Crew Retention -	Variable attenuator seat with 8-inch seat stroke including better restraint system and underfloor structure to improve occupant protection.
Troop Retention -	Standardized crashworthy troop seat with better restraint system to improve occupant protection.
Basic Airframe - Crashworthiness	Increased mass items retention capability and strengthened under-floor structure to improve vertical impact capability.
Landing Gear -	Landing gear redesigned to provide 20 fps with no airframe contact with the ground. Landing gear location optimized such that in case of failure no damage occurs to occupants or to critical systems.

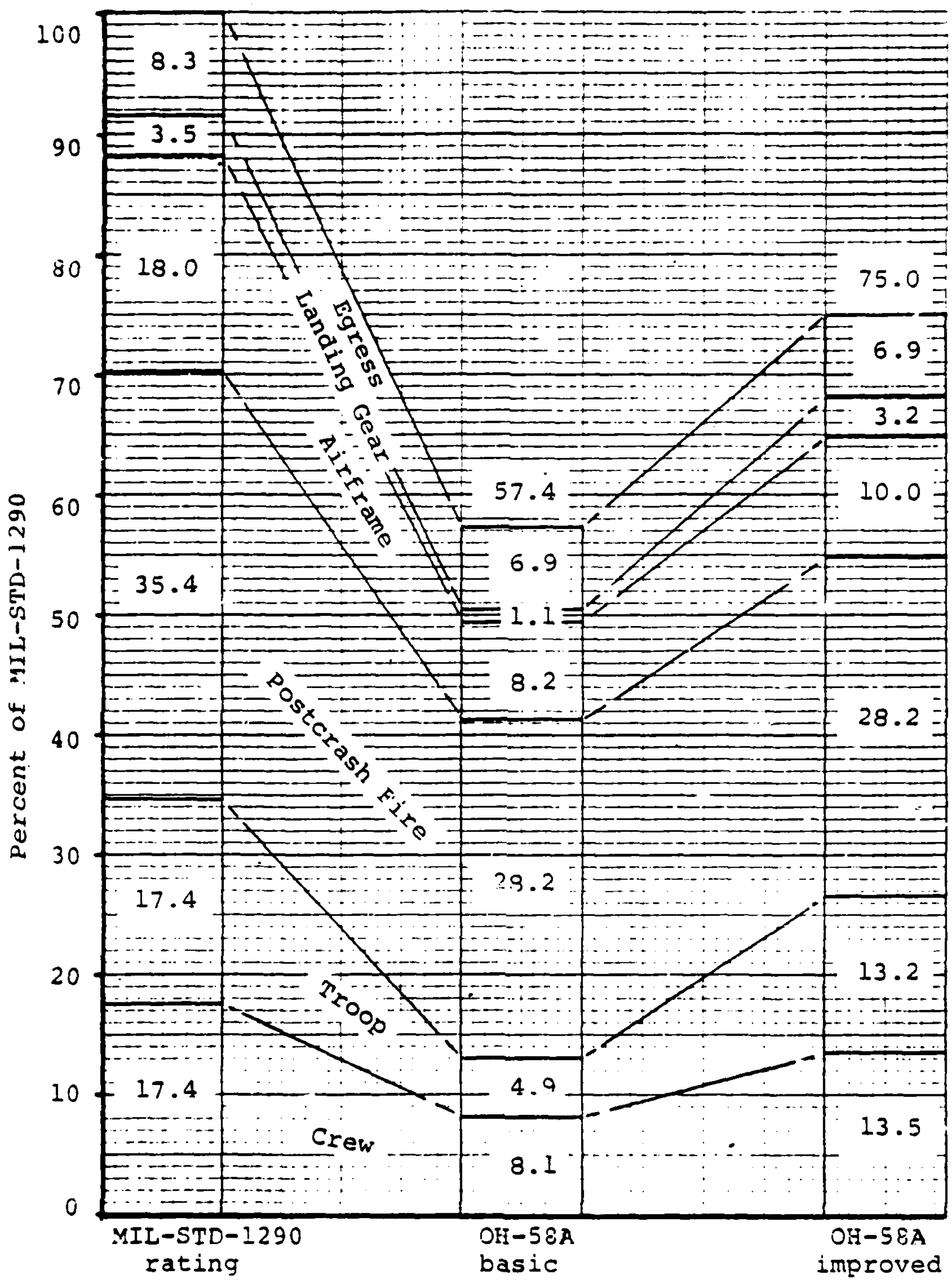

Figure 18. OH-58A rating

OH-58A IMPROVEMENTS

Crew Retention -	Variable attenuator seat with 8-inch seat stroke including better restraint system and underfloor structure to improve occupant protection.
Troop Retention -	Assume fuel cell is relocated. Standardized crashworthy troop seat with better restraint system to improve occupant protection.
Basic Airframe - Crashworthiness	Mass items retention will prevent crushing of occupied areas and will provide resistance to lateral and rollover impact loads.
Landing Gear -	Landing gear redesigned to provide 20 fps with no airframe contact with the ground. Landing gear location to be optimized such that in case of failure no damage to occupants or to critical systems.

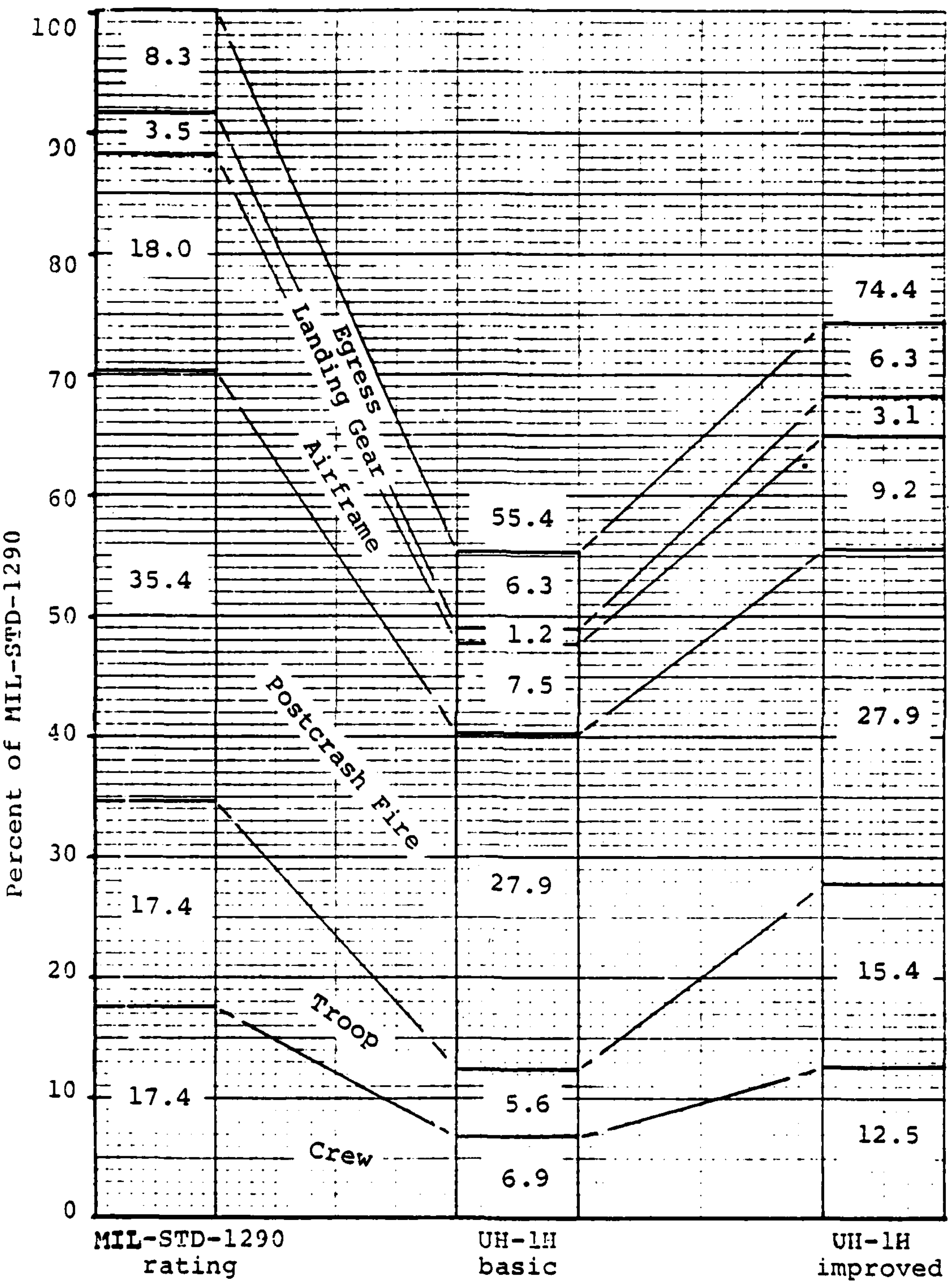

Figure 19. UH-1H rating

UH-1H IMPROVEMENTS

Crew Retention -	Variable attenuator seat with 8-inch stroke including better restraint system and underfloor structure to improve occupant protection.
Troop Retention -	Standardized crashworthy troop seat with better restraint system to improve occupant protection.
Basic Airframe - Crashworthiness	Increased mass items retention capability will provide better resistance to lateral and rollover impact loads. Also strengthened underfloor structure improves vertical impact capability.
Landing Gear -	Landing gear redesigned to provide 20 fps with no airframe contact with the ground. Redesigned forward gear relocation to cause no damage to occupants or to critical systems.

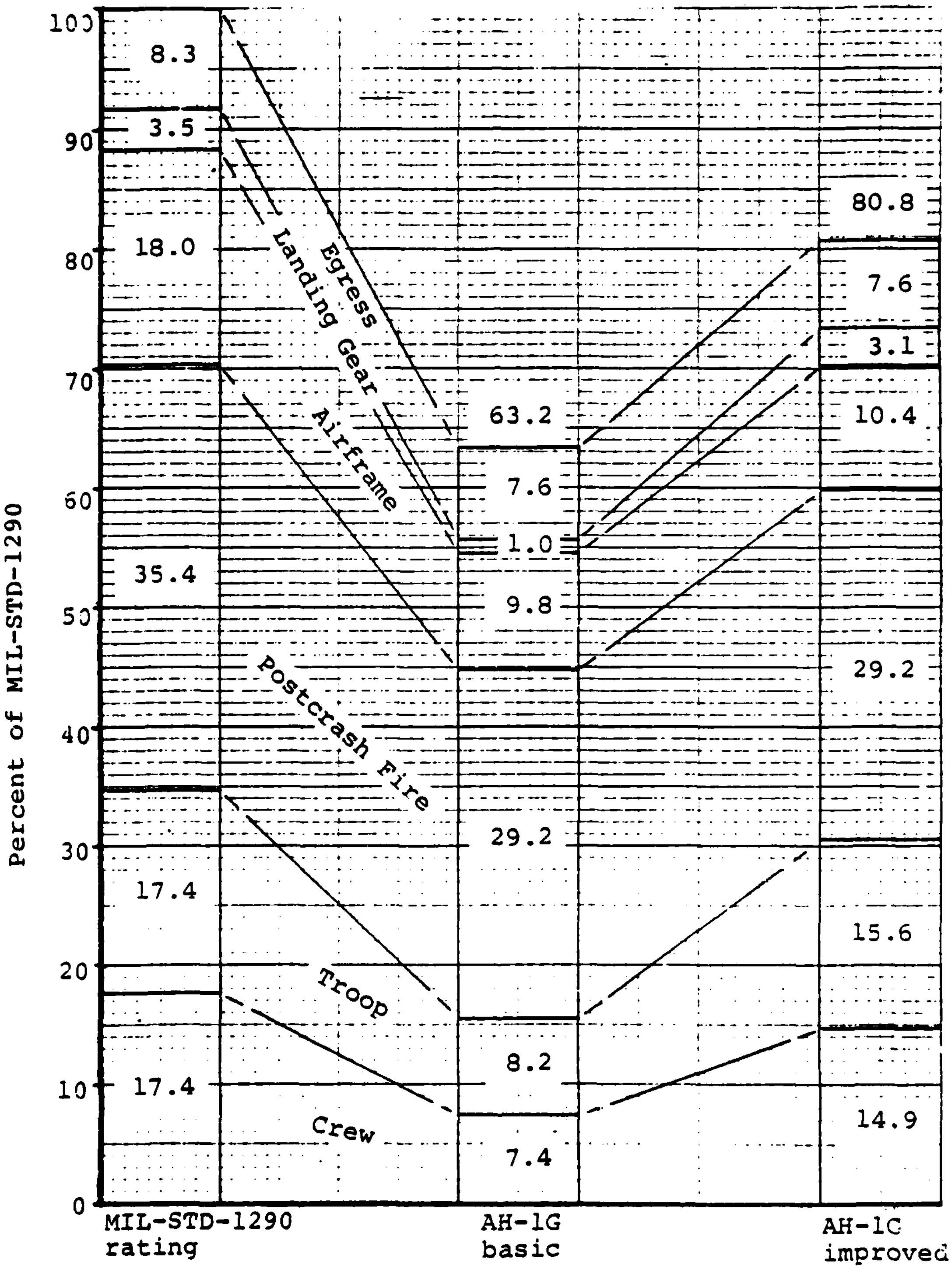

Figure 20. AH-1G rating

AH-1G IMPROVEMENTS

Crew Retention - (Pilot & Gunner)	Variable attenuator seat with 8-inch stroke including better restraint system and underfloor structure to improve occupant protection.
Basic Airframe - Crashworthiness	Increased mass items retention capability will provide better resistance to lateral and rollover impact loads and will improve resistance to vertical impact loads.
Landing Gear -	Landing gear redesigned to provide 20 fps with no airframe contact with the ground. Redesigned gear location to cause no damage to occupants or to critical systems.

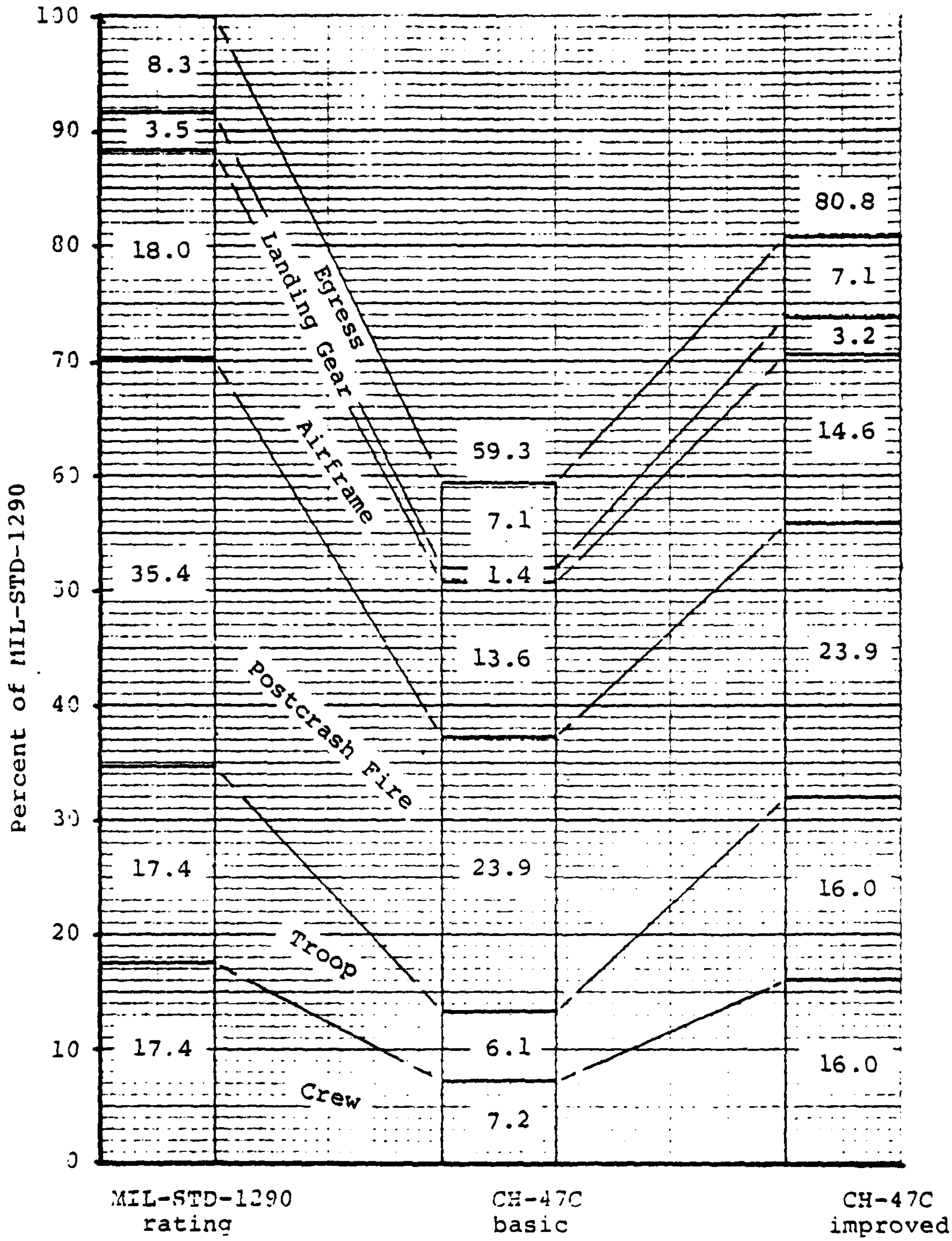

Figure 21. CH-47C rating

CH-47C IMPROVEMENTS

Crew Retention -	Variable attenuator seat with 8-inch stroke including better restraint system and underfloor structure to improve occupant protection.
Troop Retention -	Standardized crashworthy troop seat with better restraint system to improve occupant protection.
Basic Airframe - Crashworthiness	Increased mass items retention capability. Provide better resistance to lateral and rollover impact loads and strengthen underfloor structure to improve vertical impact capability.
Landing Gear -	Landing gear redesigned to provide 20 fps with no airframe contact with the ground. Redesigned forward gear relocation to cause no damage to occupants or to critical systems in a crash environment.

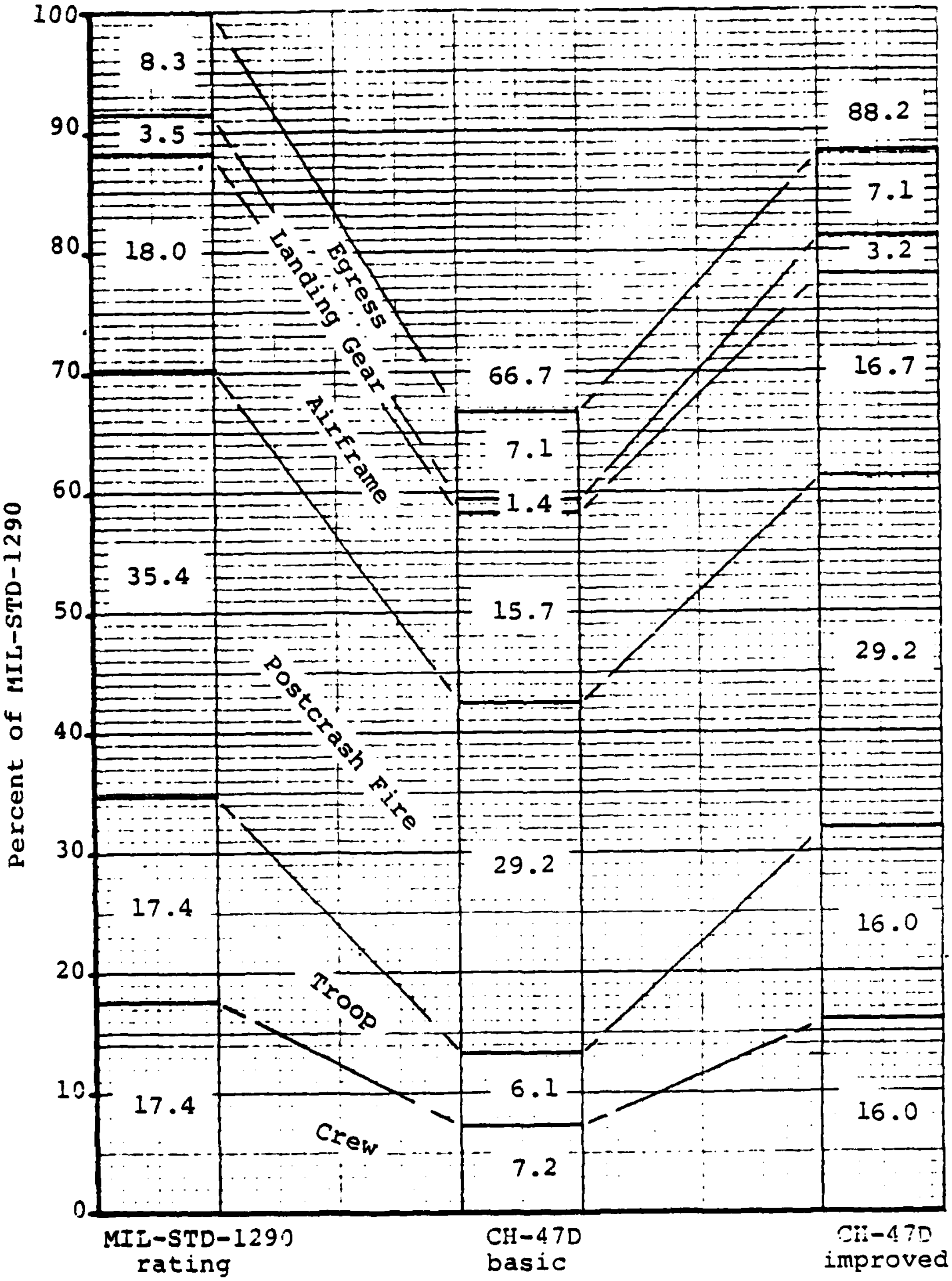

Figure 22. CH-47D rating

CH-47D IMPROVEMENTS

Crew Retention -	Variable attenuator seat with 8-inch stroke including better restraint system and underfloor structure to improve occupant protection.
Troop Retention -	Standardized crashworthy troop seat with better restraint system to improve occupant protection.
Basic Airframe - Crashworthiness	Increased mass items retention capability. Provide better resistance to lateral and rollover impact loads and strengthen underfloor structure to improve vertical impact capability.
Landing Gear -	Landing gear redesigned to provide 20 fps with no airframe contact with the ground. Redesigned forward gear relocation to cause no damage to occupants or to critical systems in a crash environment.

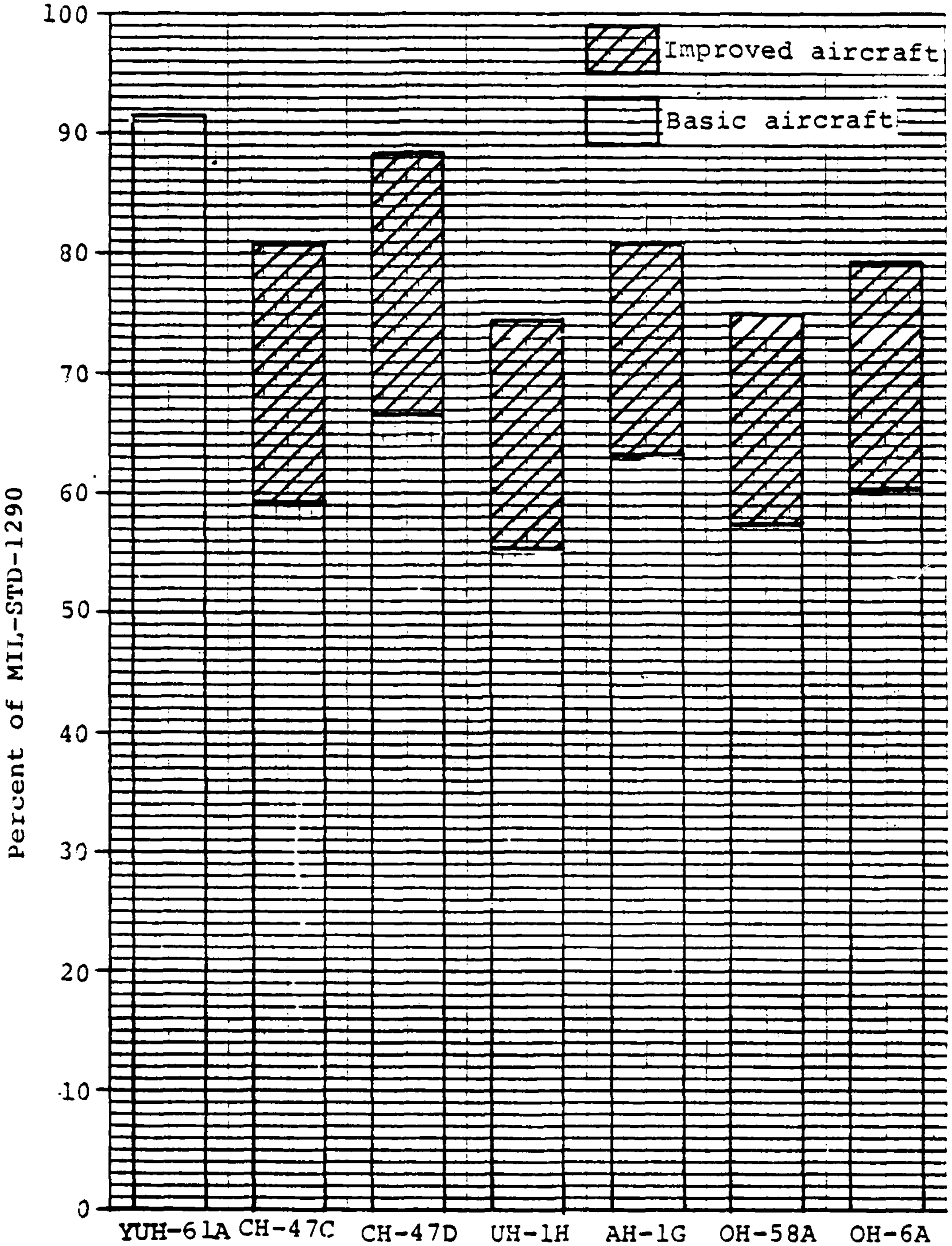

Figure 23. Aircraft comparison

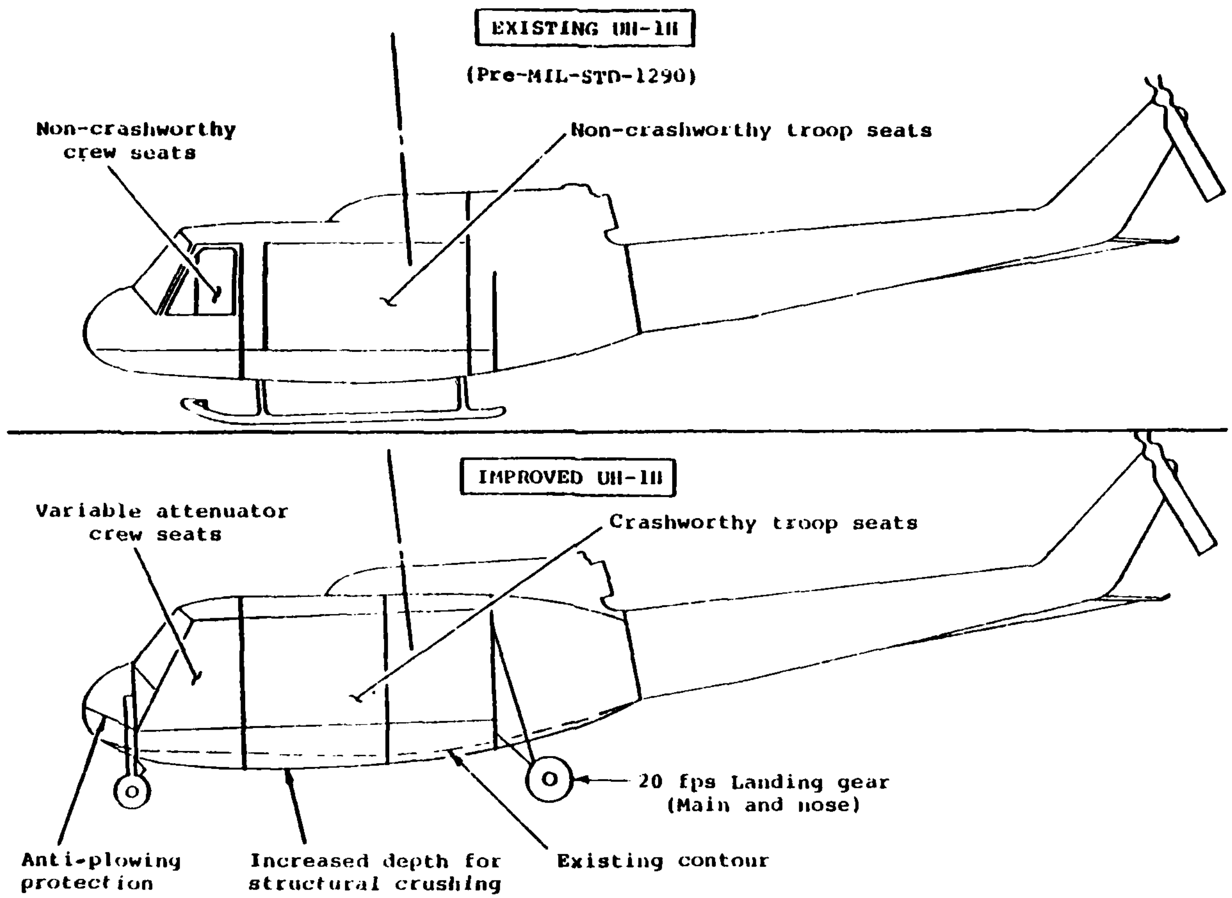

Figure 24. Example of improvements incorporated to increase crashworthiness capability

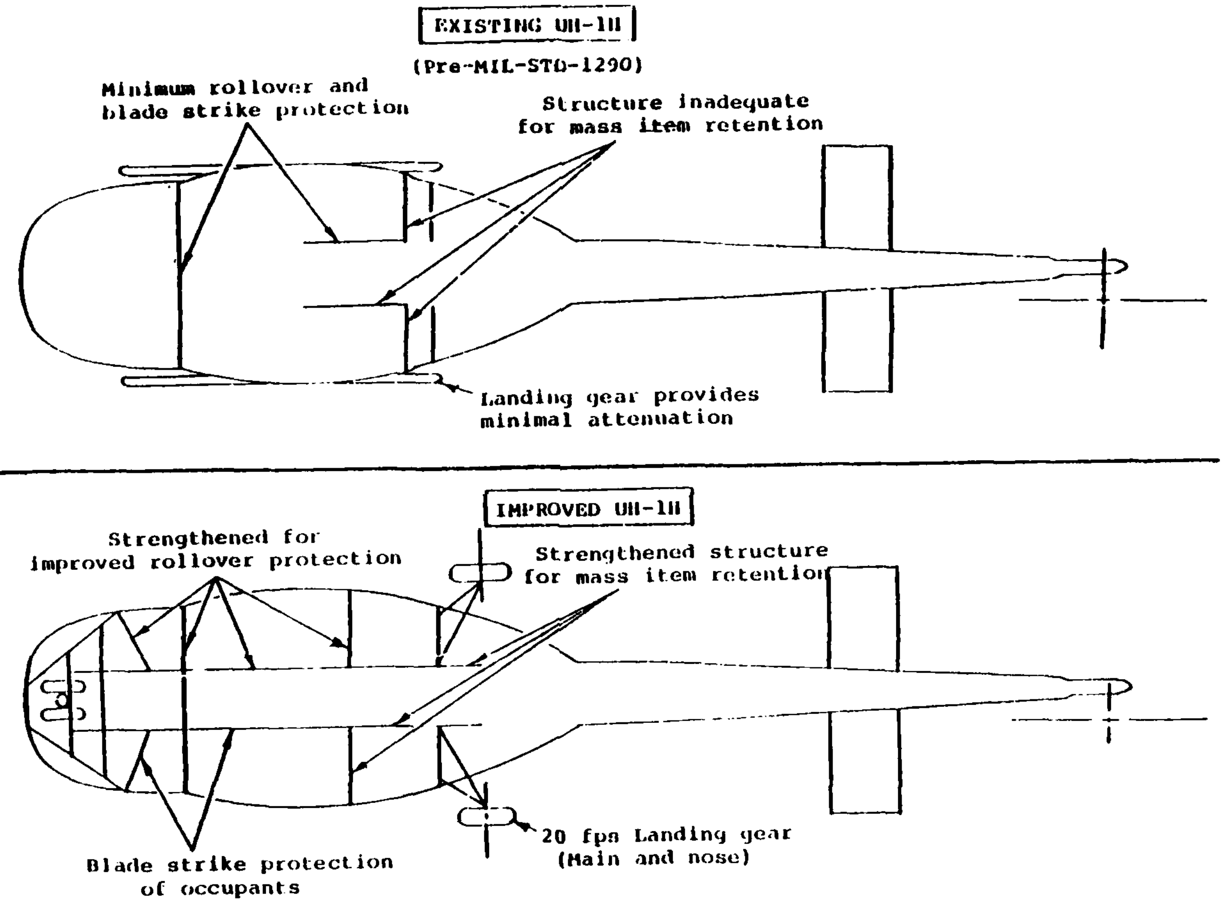

Figure 24. Continued

Casualty data from the Phase I, Task II effort together with estimates of the effects of improved crashworthiness were used to generate injury distributions and injury causal factor distributions for the five aircraft being studied. Table 16 presents injury distributions for baseline and improved aircraft for accidents where at least one injury occurred. Table 17 provides percentage distributions of casualties as functions of causal factors. Five crashworthiness parameters are included: primary structure and landing gear, seat and restraint systems, internal environment, and fire. Two other causal factors were identified from accident data that are required for the cost assessment analyses; non-survivable impact and operational problems. These distributions were obtained from actual accident report data for existing aircraft and estimates made for improved aircraft.

When estimating casualties for the improved designs, it was assumed that the number of non-survivable accidents in a given sample remained the same. For example, aircraft with the same rotor system and navigational aids are likely to experience the same rate of catastrophic accidents irrespective of the level of crashworthiness employed when the accident failure modes are respectively rotor loss and high speed impact with mountainous terrain.

Crashworthiness Cost And Weight Drivers

For the six crashworthiness parameters under consideration, previous discussion has indicated that only five needed to be considered: crew and troop seat systems, landing gear, airframe and postcrash fire prevention. Emergency egress capability is very dependent on airframe design and the distribution of structural elements and is assumed to be incorporated into the airframe. In addition egress problems are often associated with the physical layout of components. As such, a poor design can be converted to a relatively good one by redistribution, where possible, without a weight or cost penalty.

Weight estimates were obtained from weight and balance reports for each of the basic aircraft considered. Weight deltas were computed for crashworthiness improvements by using actual data, trend data, or estimating changes directly. Actual data was used for crashworthy seats and crashworthy fuel systems, trend data for landing gear growth as a function of impact velocity requirements, and estimates made for structural changes to provide sufficient restraint for large mass items, such as seats and landing gear attachments. Weight statement summaries using the

AD-A096 550 BOEING VERTOL CO PHILADELPHIA PA F/G 1/2
CRASHWORTHINESS DESIGN PARAMETER SENSITIVITY ANALYSIS.(U)
FEB 81 A E TANNER DAAK51-79-C-0042
UNCLASSIFIED D210-11676-1 USAAVRADCOM-TR-80-D-31 NL

2 OF 3
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TABLE 16. INJURY DISTRIBUTIONS FOR BASELINE AND IMPROVED AIRCRAFT DESIGNS

A/C	TOTAL ACC.	TOTAL OCCUP.	TOTAL INJURIES			FAT. DUE TO FIRE*	FAT. NON-SURV. ACC. (IMPACT)⊕	FAT. SURV.ACC. (IMPACT)	TOTAL INJURIES (F, S & M)
			F	S	M				
OH-6A	68	171	28 (11)	42 (22)	74 (40)	8 (0)	7 (7)	13 (4)	144 (73)
OH-58A	55	134	52 (29)	40 (25)	31 (20)	13 (0)	24 (24)	15 (5)	123 (74)
UH-1H	104	577	134 (66)	100 (63)	137 (87)	24 (0)	46 (46)	64 (20)	371 (216)
AH-1G	70	138	50 (35)	29 (16)	42 (22)	10 (0)	33 (33)	7 (2)	121 (73)
CH-47	18	93	35 (24)	14 (7)	28 (13)	8 (0)	23 (23)	4 (1)	77 (44)

<u>Assumptions for improved A/C</u>:

* will be eliminated for C/W fuel system
⊕ will remain same assuming same % non-surv. accidents
( ) values for improved MIL-rating

TABLE 17. PERCENTAGE INJURY DISTRIBUTIONS (FROM DATA AND ESTIMATED FOR IMPROVED CRASHWORTHINESS)

AIRCRAFT	OH-6A		OH-58A		UH-1H		AH-1G		CH-47	
% *MIL-STD-1290*	60	79	57	75	55	74	63	81	59	81
Primary Structure & Landing Gear	47	39	28	26	49	45	29	28	12	5
Seat & Restraint Systems	9	4	11	5	10	6	12	4	15	3
Internal Environment	19	27	29	35	22	27	19	18	18	22
Operational Problems (People)	14	20	1	2	1	1	5	5	15	18
Fire	6	0*	11	0*	6	0*	8	0*	10	0*
Non-Survivable Impact	5	10	20	32	12	21	27	45	30	52

*assumed no explosive fires which inhibit egress (*C/W fuel system*)

subdivisions defined in Reference 32 are contained in Table 18 for the baseline and improved aircraft.

Cost estimates were made for the baseline aircraft by using the weight statement breakdowns in conjunction with Reference 33. Values obtained for the mean empty weight of each aircraft were factored to reflect actual known acquisition costs and to express the results in 1980 dollars. Improved crashworthiness cost deltas were computed for relevant elements of the weight statement, the remainder being constant, using the Reference 33 methodology, and adding increments considered relevant for increases due to manufacturing complexity or new features such as crashworthy seats.

Percentage of crashworthiness values were plotted against element weights for all of the aircraft in the sample. Characteristics were obtained for crashworthiness element weights as functions of MIL-STD-1290 for seat installations and as functions of MIL-STD-1290, mean empty weight and aircraft gross weight for landing gear and structure. It proved necessary to express the data in this way since seats are substantially the same for all aircraft installations but structure and landing gear vary as functions of gross weight and mean empty weight. It was found during the analysis that the mean empty weight was the better parameter to use as a baseline since this represented the actual hardware to be made, the ultimate gross weight being determined by mission requirements, fuel capacity, payload, etc.

Representation of fuel system weight data necessitated the use of a different approach because the fuel capacity of an aircraft design can be tailored to a given mission requirement. This results in differing fuel capacities for aircraft of the same gross weight. The ratio of fuel system weight to fuel weight was plotted as a function of aircraft gross weight and level of crashworthiness. There is not an appreciable difference in overall system weight whether a

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[32] Military Standard, MIL-STD-1374A, WEIGHT AND BALANCE DATA REPORTING FORMS FOR AIRCRAFT (INCLUDING ROTORCRAFT), Department of Defense, Washington, D.C., 20301, September 1977.

[33] PARAMETRIC STUDY OF HELICOPTER AIRCRAFT SYSTEMS COSTS AND WEIGHTS, NASA CR 152315, National Aeronautical and Space Administration, Ames Research Center, Moffett Field, California, January 1980.

TABLE 18. WEIGHT STATEMENT SUMMARIES FOR BASELINE AND IMPROVED AIRCRAFT

ELEMENT \ AIRCRAFT	OH-6A		OH-58A		UH-1H		AH-1G		CH-47C		CH-47D		YUH-61A
	BASELINE	IMPROVED*	BASELINE	IMPROVED*	BASELINE	IMPROVED*	BASELINE	IMPROVED*	BASELINE	IMPROVED*	BASELINE	IMPROVED*	BASELINE
WING							121.3						
ROTOR	176.6		277.0		730.6		923.1		3420.0		3634.9		1849.0
TAIL													
SURFACES	21.5		25.2		25.0		28.4						223.6
ROTOR	7.0		8.3		30.8		30.8						105.0
BODY													
BASIC	156.2	208.7	221.7	259.0	649.4	782.0	704.0	808.0	2483.0	2997.4	2490.4	3004.8	1157.5
SECONDARY	72.6		90.4		427.2		214.7		2113.0		2112.0		534.9
ALIGHTING GEAR GROUP	60.1	90.1	33.2	68.2	120.9	220.9	117.4	217.4	1132.0	1532.0	1124.0	1524.0	508.3
ENGINE SECTION	12.4		32.0		159.0		162.3		284.0		284.0		267.5
PROPULSION GROUP													
ENGINE INST.	151.0		138.1		538.7		[illegible]		1430.0		[illegible]		[illegible]
EXHAUST SYSTEM	8.6		4.0		13.0		10.0		40.0		40.4		21.6
COOLING	0.5		-		-		6.4		-		-		-
CONTROLS	6.4		10.6		17.2		16.4		84.0		86.2		36.1
STARTING	0.3		17.5		50.0		49.8		107.0		88.7		60.0
	-		-		-		-		-		-		-
LUBRICATING	19.0		22.6		61.4		57.6		23.0		24.6		21.0
FUEL	107.0		87.8		266.1		197.4		1931.0		1738.5		381.6
DRIVE	120.0		184.5		601.3		586.0		3682.0		4174.9		1650.2
FLIGHT CONTROLS	68.4		133.3		356.7		382.2		1654.0		1736.0		965.2
AUX POWER PLANT									106.0		116.2		148.5
INSTRUMENTS	26.4		29.9		54.6		110.3		209.0		244.7		159.7
HYDR & PNEUMATIC					39.0		91.0		228.0		264.6		92.4
ELECTRICAL GROUP	63.0		109.3		361.3		187.7		527.0		642.2		361.4
AVIONICS GROUP	109.8		50.9		267.9		159.7		332.0		366.8		436.0
FURN & EQUIP GROUP													
ACCOM FOR PERSON	20.8	141.8	40.2	163.8	140.1	223.6	42.3	120.1	394.0	699.0	390.0	695.0	469.7
MISC EQUIPMENT	7.4		3.7		49.7		22.3		118.0		115.1		68.6
FURNISHINGS	10.3		8.4		30.8		1.5		955.0		754.5		220.9
EMERG EQUIPMENT	8.9				17.2		12.7		70.0		72.3		52.3
AIR CONDITIONING			27.1		43.9		48.4		146.0		146.7		65.6
ANTI-ICING GROUP	8.0								44.0		45.4		41.1
LOAD AND HANDLING GP					2.5		2.5		266.0		402.1		48.4
WEIGHT EMPTY	1,242.2	1,445.7	1,555.7	1,751.6	5,054.3	5,370.4	4,798.6	5,080.4	21,778.0	22,997.4	[illegible]	23,834.6	10,779.[illegible]
CREW													
TRAPPED LIQUIDS													
ENGINE OIL													
FUEL													
GROSS WEIGHT	2,400.0	2,400.0	3,000.0	3,000.0	9,500.0	9,500.0	9,500.0	9,500.0	46,000.0	46,000.0	50,000.0	50,000.0	10,249.0

*CHANGES TO BASELINE LISTED IN THIS COLUMN. ALL OTHER VALUES REMAIN THE SAME.

self-sealing tank is used or not since the fuel tank represents 25 to 30 percent of the total system weight. The number of fuel tanks used, the proximity of them to the engine(s), and their location in the airframe, under the floor or high above the ground plane for example, all tend to cause variability in the system weight.

Figures 25 through 29 give weight characteristics for seats, landing gear, structure and fuel system, and a summation of the structural elements is contained in Figure 30.

Cost information has been subdivided into three categories: procurement, accident and life-cycle costs for each element. In all cases injuries attributable to the element, as noted in the injury causal factor distribution, were assessed. These data are presented in the next section of life-cycle cost analysis.

Seat injury causal factors were assessed to identify the accident cost as a variation of level of crashworthiness characteristic. This allows the contribution by each element, seats and landing gear structure, to be reviewed to identify areas where more attention is needed to improve the design and overall crashworthiness. Landing gear and structure were assessed as a composite entity for cost analysis with respect to injury potential since the data overviewed did not segregate injury causal factors for the two.

To provide data for the modern trend in airframe construction where composite materials are used, estimates were made for airframe weight variation with crashworthiness rating. These data are presented in Figure 31 for aircraft up to 50,000 pounds gross weight.

LIFE-CYCLE COST OF CRASHWORTHINESS

Life-cycle cost in the context of this study is comprised only of the costs of buying crashworthiness-affecting features, plus the resulting accident costs. This decision was made in order to be able to concentrate specifically on the subject matter of the study. Otherwise crashworthiness cost benefits would be hidden in the total life-cycle costs. (For example, life-cycle crashworthiness costs for a fleet of 436 Chinooks is estimated to be in the area of $800 million, whereas total Chinook life-cycle costs for a fleet of 436 aircraft are close to $10 billion.)

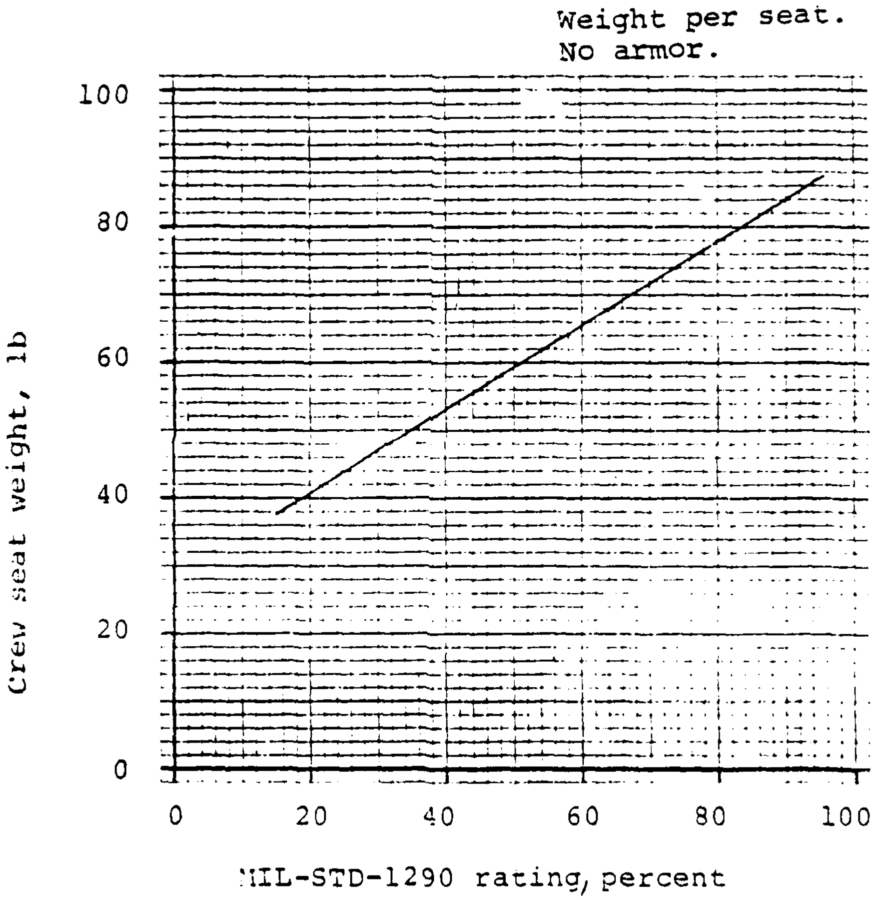

Figure 25. Crew seat weight variation with crashworthiness rating.

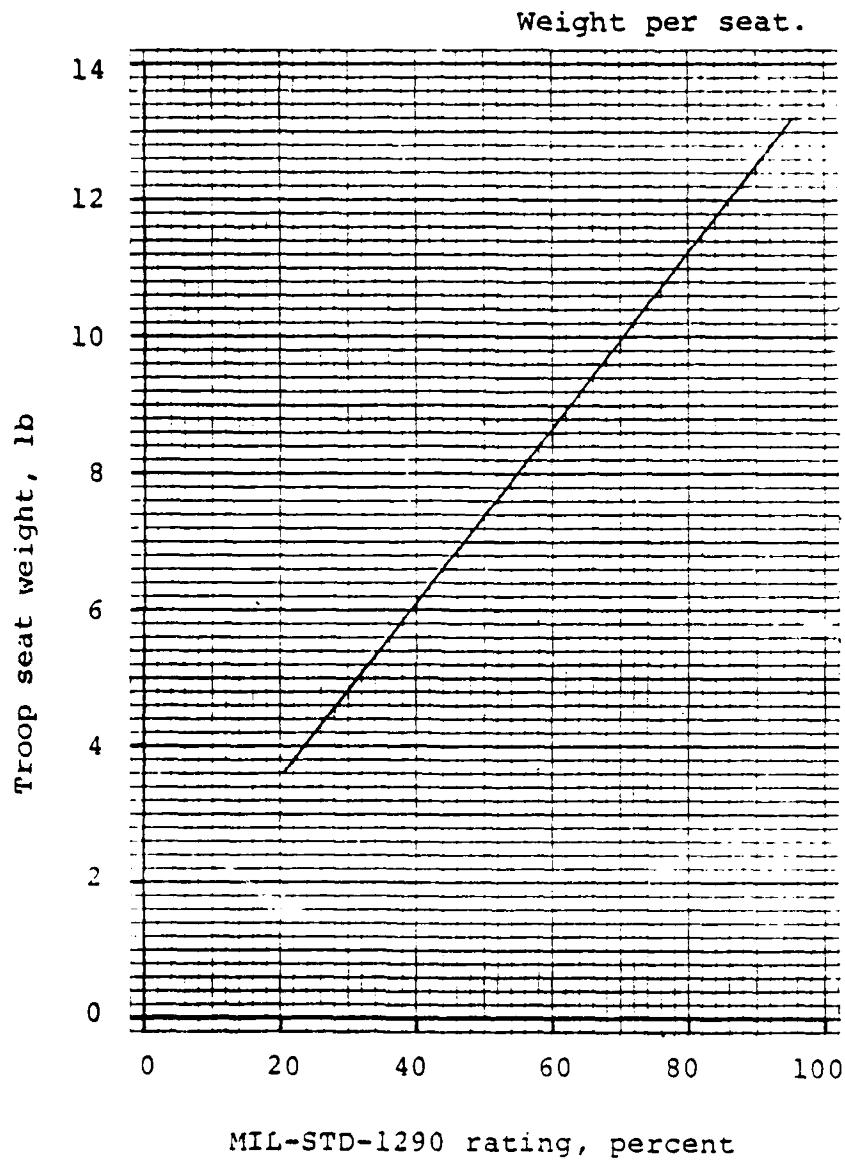

Figure 26. Troop seat weight variation with crashworthiness rating.

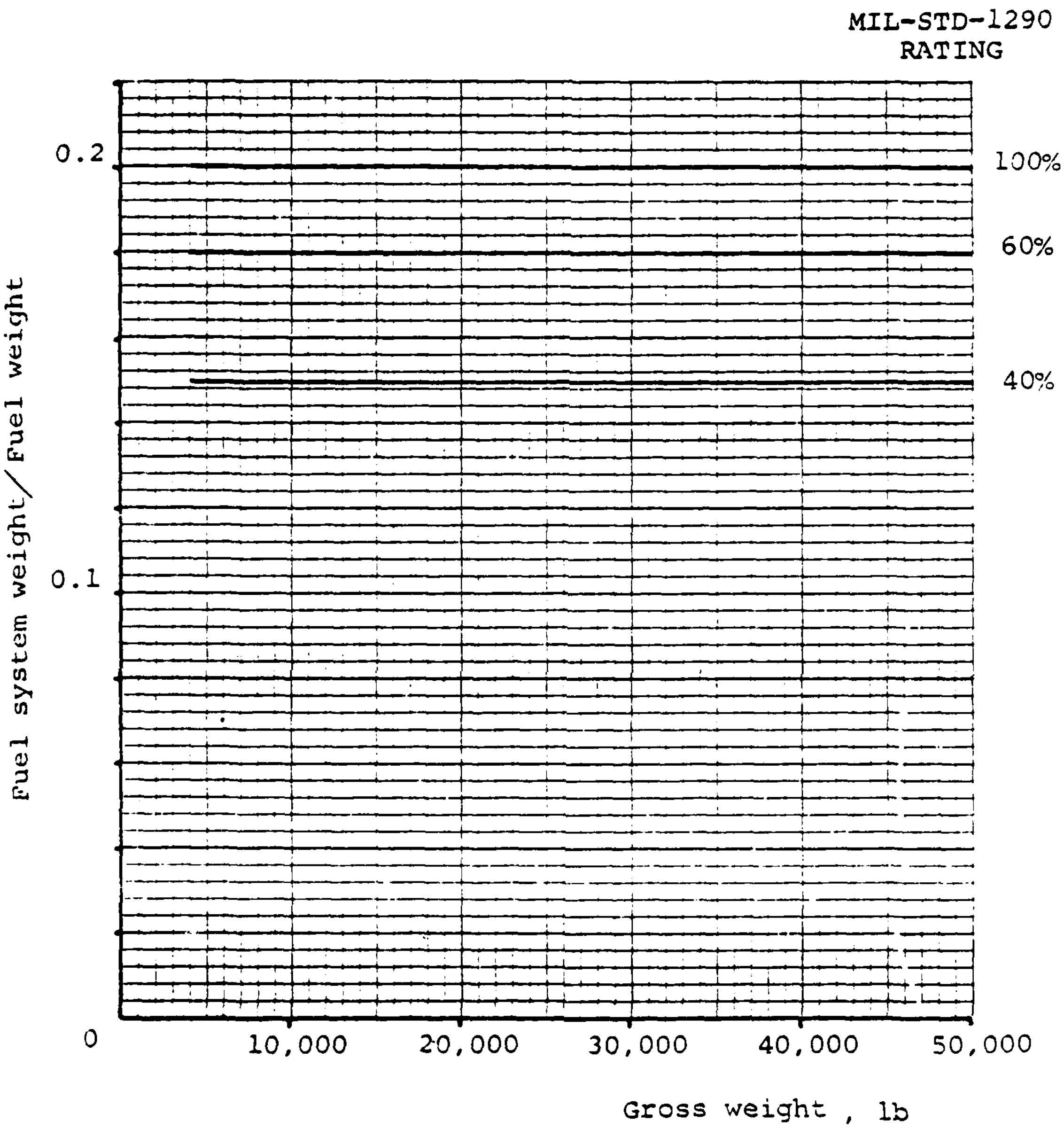

Figure 27. Fuel system weight variation with crashworthiness rating.

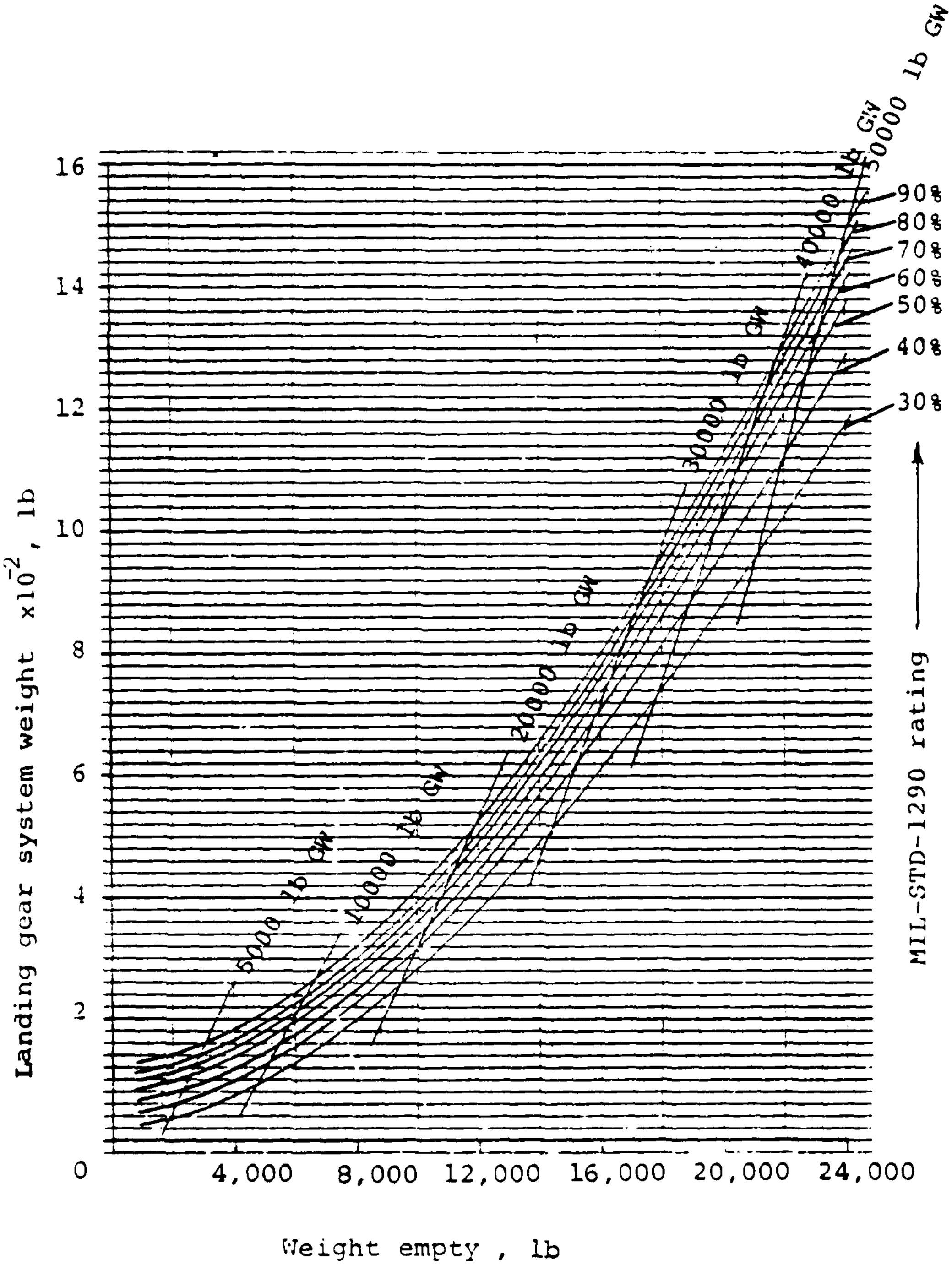

Figure 28. Landing gear system weight variation with crashworthiness rating.

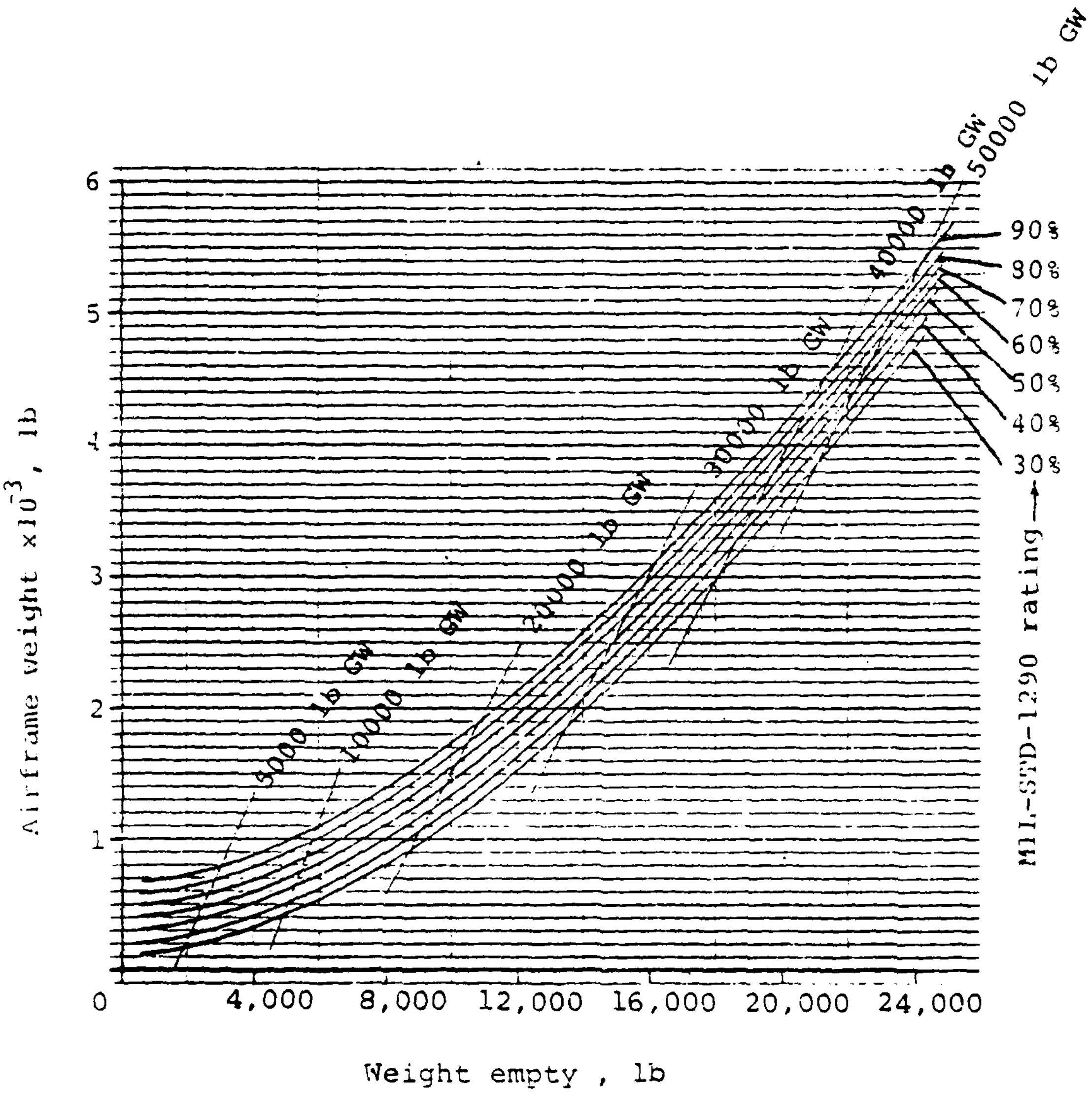

Figure 29. Metal airframe weight variation with crashworthiness rating.

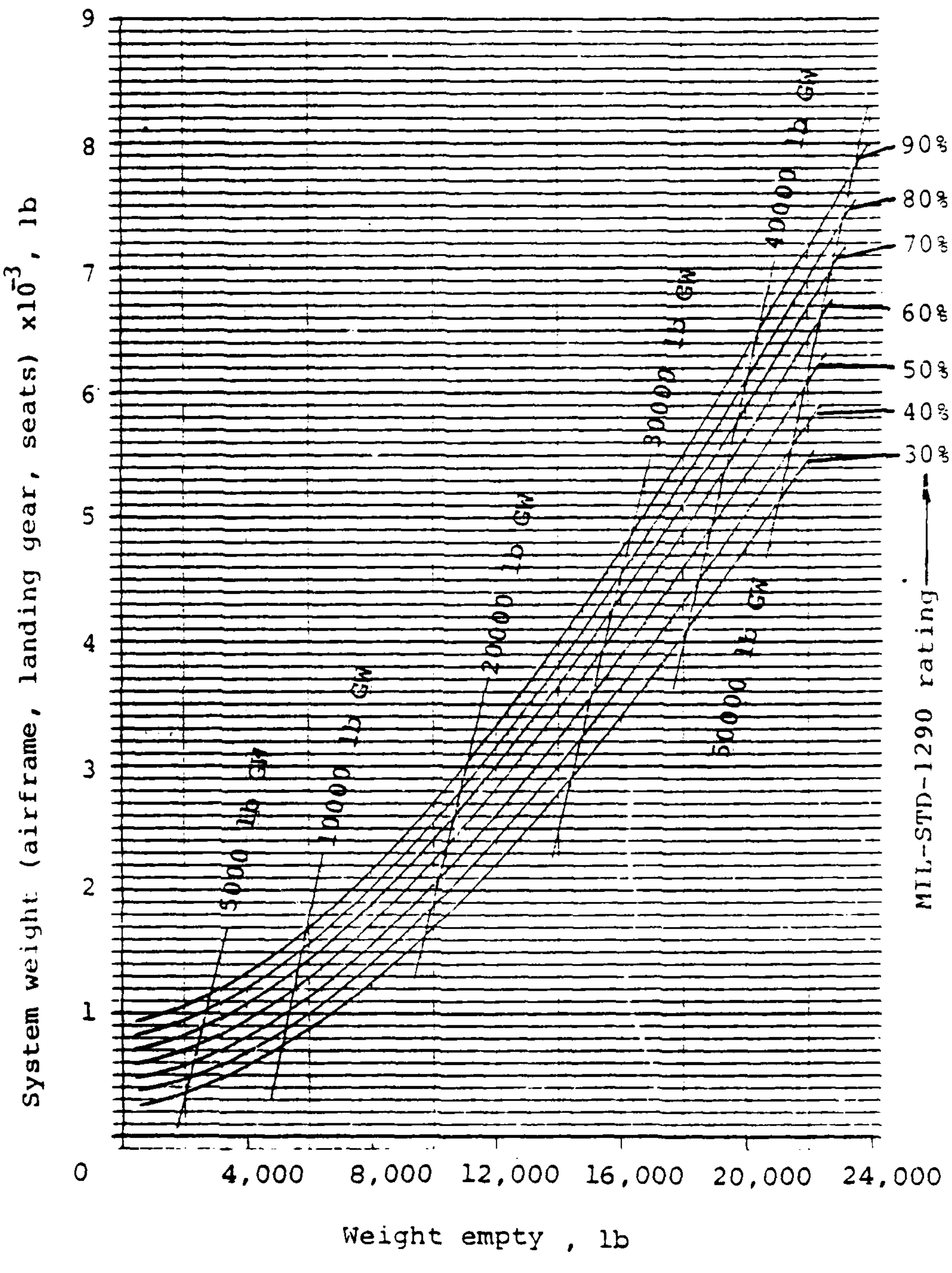

Figure 30. Aircraft system weight variation with crashworthiness rating.

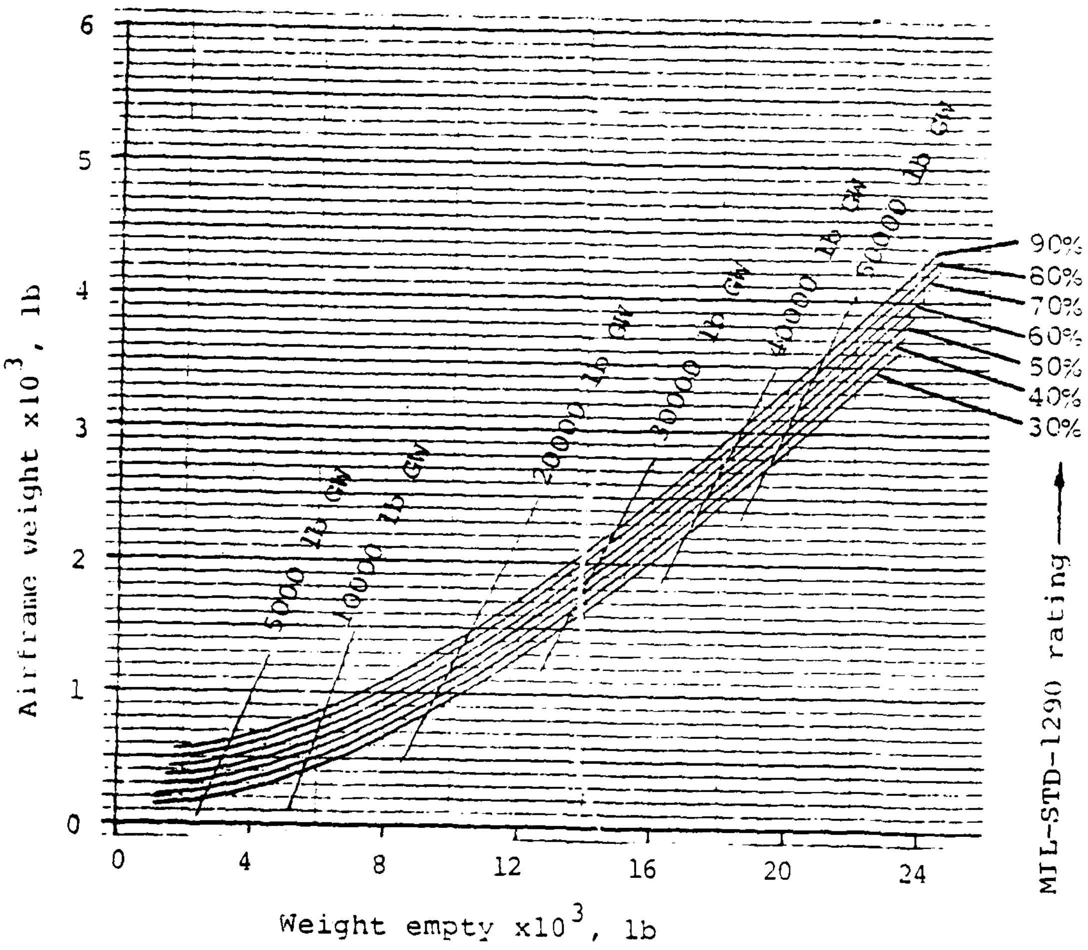

Figure 31. Composite airframe, weight variation with crashworthiness rating.

Acquisition Cost

Acquisition cost is defined herein as the recurring cost of initially buying the crashworthiness-affecting (CA) features of the aircraft. These features are: crew seats, troop seats, landing gear, airframe (structure), and fuel system.

It is postulated that higher levels of crashworthiness will generally result in increased aircraft weight, and that higher aircraft weight will generally result in higher aircraft cost. Cost estimating relationships (CER's) were developed for the acquisition cost of CA features, based on the NASA model described in the Reference 33 report. These were adjusted based on the limited cost data supplied by AVRADCOM, St. Louis, and the limited cost data available in-house at Boeing Vertol. Airframe costs for the baseline were estimated at 25% of total aircraft costs, based on the Reference 34 report.

Table 19 shows the empty weight (EW), percentage of Military Standard 1290 rating (PMSR), and estimated cost of CA features for the baseline and improved aircraft. Additional supporting data are contained in Appendix I. All dollars in this report are 1980 dollars.

Figures 32 through 35 are trend curves for acquisition cost for the four categories of CA features, plotting acquisition cost against weight empty. Figure 32 provides cost data for seats only as a level of crashworthiness since seat requirements do not vary with the size of the aircraft. To use this figure, determine the PMSR and read off the crew and troop seat acquisition cost, then multiply by the number of seats. Landing gear cost is related to gear weight as shown in Figure 32, a more crashworthy gear being heavier for a given aircraft configuration. To use the other curves, determine the aircraft empty weight and PMSR, and read off the acquisition costs, then multiply by the quantity of aircraft.

Figure 32 is sensitive to crashworthiness level only in the sense that higher levels of crashworthiness result in higher weight and higher cost. When all of the data points (10) were plotted from the CER's, it was possible to fit a single line through the data, rather than a 60% line for the baseline configurations and an 80% line for the improved configurations.

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[34] ARMY HELICOPTER COST DRIVERS, USAAMRDL-TM-7, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, 23604, August 1975.

TABLE 19. ACQUISITION COSTS FOR CRASHWORTHINESS-AFFECTING FEATURES FOR BASELINE AND IMPROVED AIRCRAFT

Aircraft	Baseline			Improved		
	EW	PMSR	$	EW	PMSR	$
OH-6	1,499	60	77,092	1,802	79	108,192
OH-58	1,769	57	86,774	2,045	75	117,820
UH-1	4,673	55	196,786	5,110	74	241,275
AH-1	4,879	63	276,005	5,239	81	327,891
CH-47	20,890	59	1,664,260	21,953	81	1,795,924

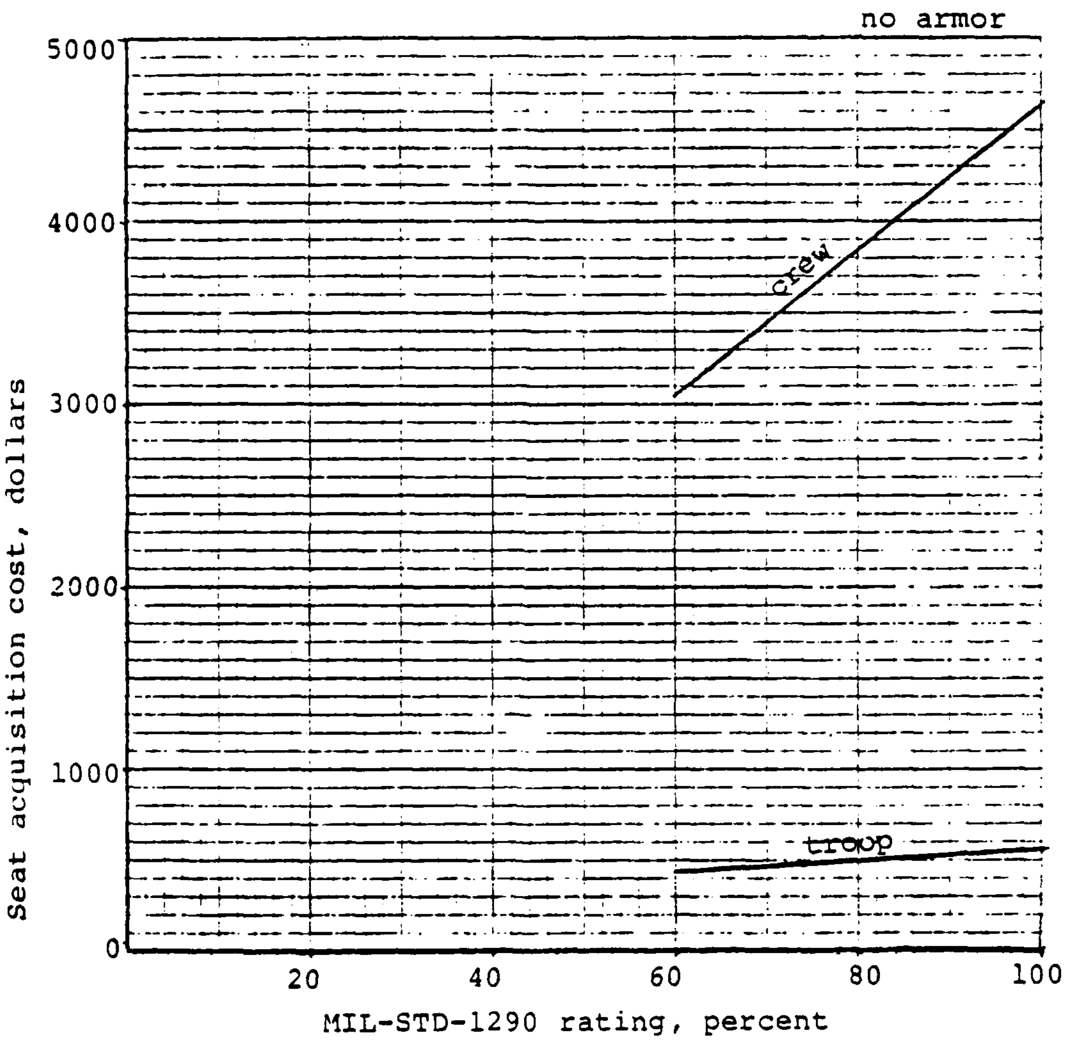

Figure 32. Seat acquisition cost variation with crashworthiness rating

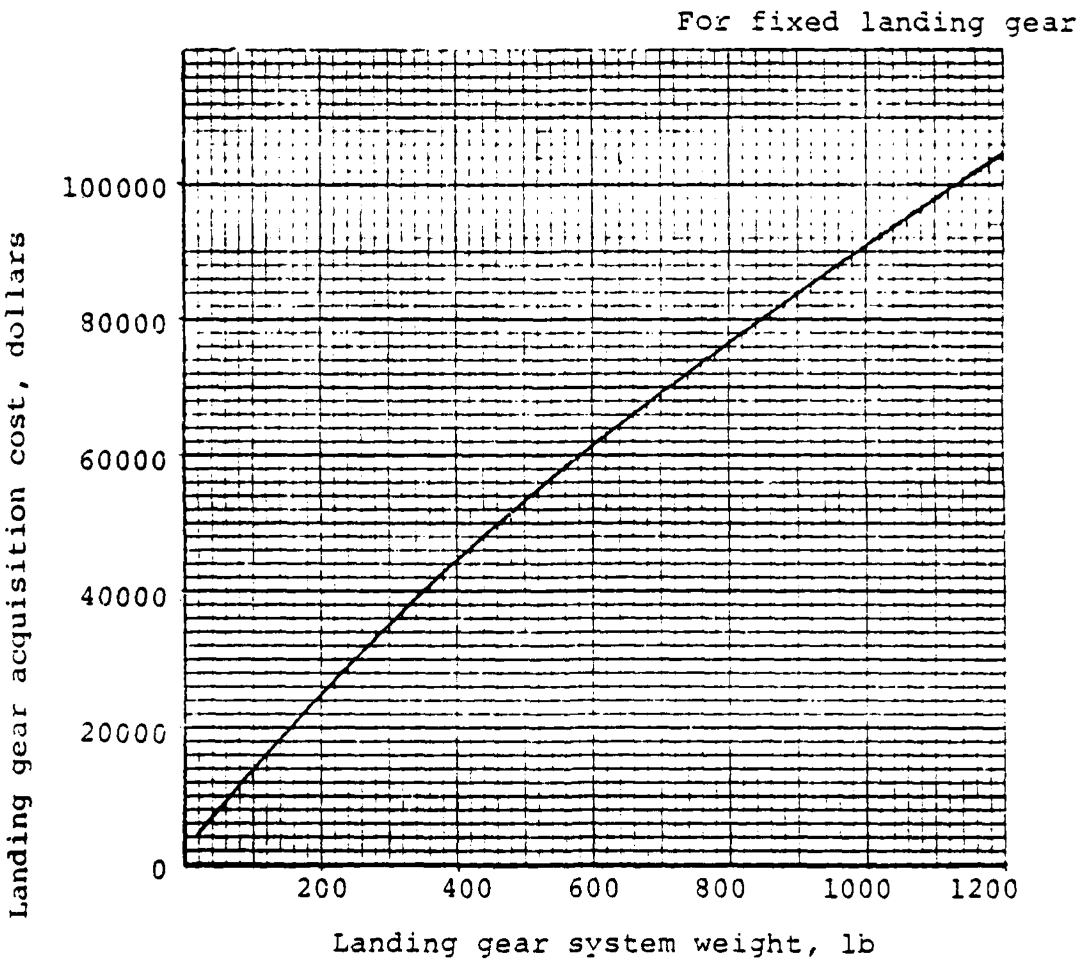

Figure 33. Landing gear acquisition cost variation with weight

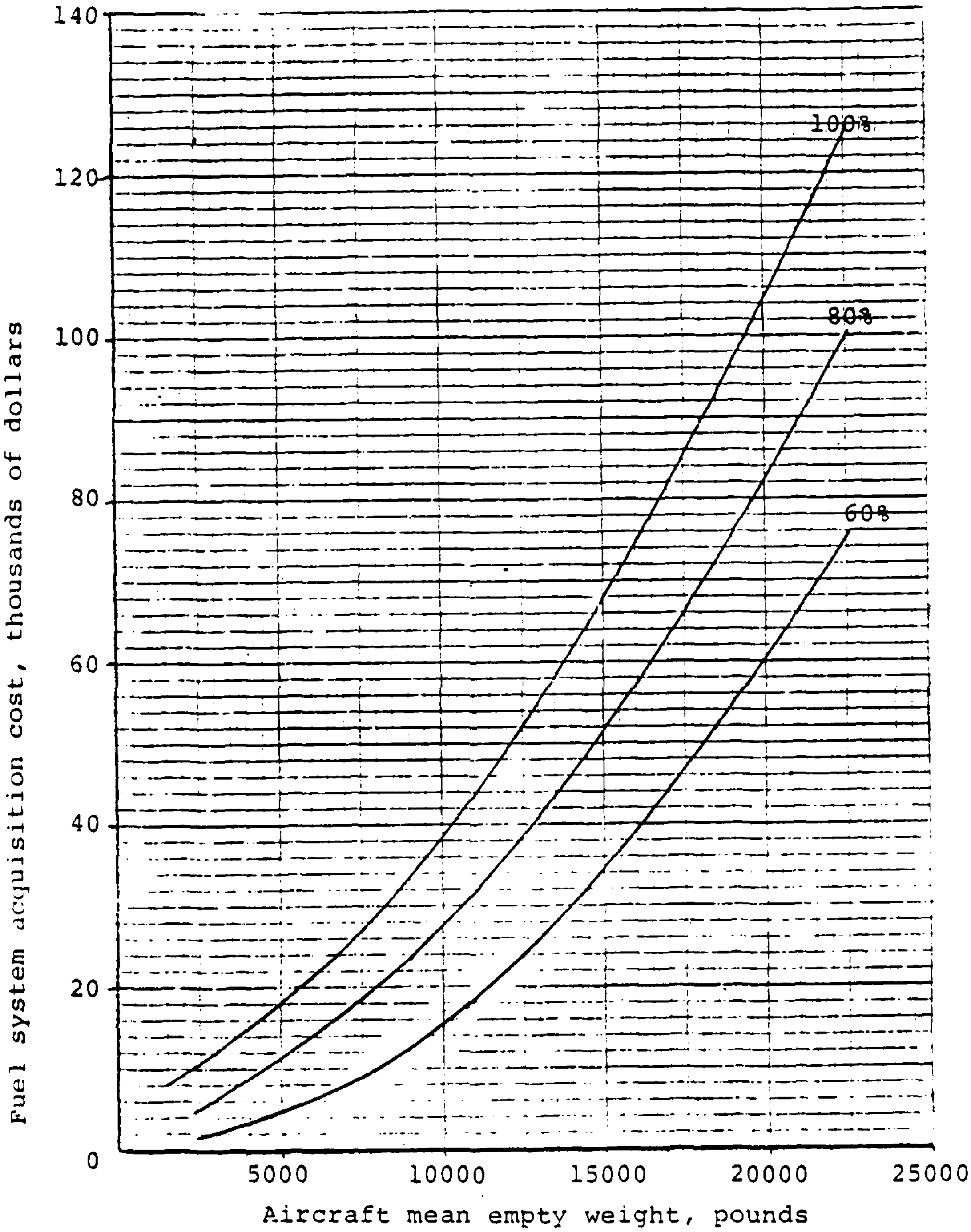

Figure 34. Fuel system acquisition cost variation with crashworthiness rating

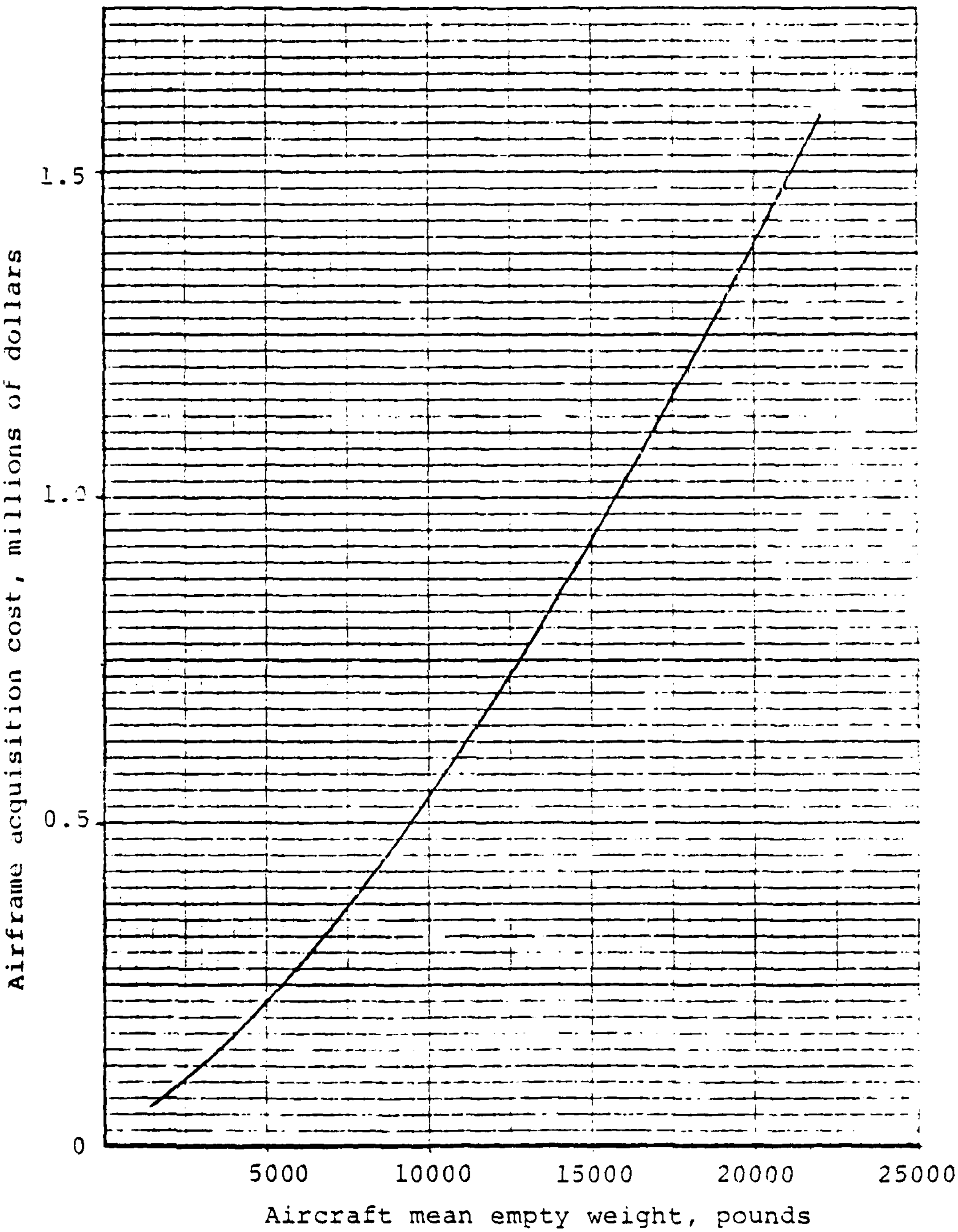

Figure 35. Airframe acquisition cost variation with aircraft mean empty weight

Regarding Figure 35 and other figures in the report which show three levels of crashworthiness, the data from the five baseline aircraft configurations comprise the 60% PMSR curve, the data from the five improved aircraft configurations comprise the 80% PMSR curve, and the 100% PMSR curve is estimated.

Total CA feature acquisition cost is the sum of the four. A figure representing total CA feature acquisition cost can not be presented, since the number of seats is variable depending on aircraft configuration.

Accident Costs

Accident costs have been calculated, representing the average cost per accident for aircraft of various weight and crashworthiness level. In order to use the data the user must know the empty weight, PMSR, and the expected number of accidents the fleet of aircraft will experience over the life cycle. In order to develop the data, accident costs were divided into injury costs and material damage costs.

Injury Costs

Accidents can cause injuries with varying levels of severity. In this study injuries can be fatal, major, or minor. Table 20 displays the level of severity for the baseline aircraft accidents used as the basis for this study. The injuries were estimated for the improved design.

Injuries can be said to be caused by six different factors in the context of this study. The historical accident data were analyzed, and judgements were made as to what factor of the six was most responsible for the injury. This information is shown for the baseline aircraft in Table 21. This table also displays estimates for the improved aircraft. For costing purposes, it was assumed that the fire and nonsurvivable impact categories represented accidents which always resulted in fatalities. These fatalities were then subtracted from the total number injured, and the remaining fatalities and injuries were spread over the other four causal factors. Additional details are shown in Appendix I.

Fatalities and injuries can occur to both helicopter crew members and troops. The distribution of fatalities and injuries between crew members and troops was obtained from a summary based on U.S. Army Aviation Mishap Reports covering the period from 1971 to 1975. It was assumed that the distribution of injuries between crew and non-crew would be the same regardless of whether the injury was major or minor.

TABLE 20. INJURY DISTRIBUTIONS FOR BASELINE AND IMPROVED AIRCRAFT

Aircraft	Accidents	Occupants	Baseline			Improved		
			Fatalities	Major	Minor	Fatalities	Major	Minor
OH-6	68	171	28	42	74	11	22	40
OH-58	55	134	52	40	31	29	25	20
UH-1	104	577	134	100	137	66	63	87
AH-1	70	138	50	29	42	35	16	22
CH-47	18	93	35	14	28	24	7	13

TABLE 21. PERCENTAGE DISTRIBUTIONS OF INJURY CAUSAL FACTORS FOR BASELINE AND IMPROVED AIRCRAFT

Causal Factor	OH-6		OH-58		UH-1		AH-1		CH-47	
	Base.	Impr.	Base.	Impr.	Base.	Impr.	Base.	Impr.	Base.	Impr.
Airframe & Landing Gear	47	39	28	26	49	45	29	28	12	5
Seat & Restraint Systems	9	4	11	5	10	6	12	4	15	3
Internal Environment	19	27	29	35	22	27	19	18	18	22
Operational Problems	14	20	1	2	1	1	5	5	15	18
Fire	6	0	11	0	6	0	8	0	10	0
Non-survivable Impact	5	10	20	32	12	21	27	45	30	52

The estimated percentage of crew and troops killed and injured is shown in Table 22 and the costs associated with the injury severity levels are shown in Table 23, from Reference 35.

The data in all of the previous tables were combined to calculate the average cost of injuries per aircraft accident, for the baseline and improved aircraft, by injury causal factor. This data is displayed in Table 24. Additional details are shown in Appendix I.

Material Damage Costs

For costing purposes it was assumed that an aircraft involved in an accident was either stricken or repaired. This is obvious, but the understanding of this dichotomy facilitates the understanding of the accounting of material damage costs. Accidents are then costed at either the aircraft acquisition cost (for strikes), or the average repair cost (for non-strikes). Table 25 shows the percentage distribution between strikes and repairable accidents. For the baseline aircraft, this distribution is based on Safety Center data between 1971 and 1975. It is interesting to note that the strike rate may not be indicative only of the crashworthiness level of the aircraft, but also of the acquisition cost of the aircraft. As will be shown in a later table, the more expensive the aircraft is, the smaller is the percentage of acquisition cost which is permitted to be spent on repair of the aircraft. The strike rate for the improved aircraft was estimated based on the following assumptions:

1. Baseline non-survivable impact accidents were all strikes, and there would be no improvement in the number of non-survivable impact accidents, nor their severity.

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[35] MISHAP INVESTIGATION REPORTING AND RECORD KEEPING, DOD Instruction 1000.19, Department of Defense, Washington, D.C., 20302, 18 October 1979.

TABLE 22. PERCENTAGE OF CREW & TROOPS KILLED AND INJURED

AIRCRAFT	FATALITIES		INJURIES	
	CREW	TROOP	CREW	TROOP
OH-6	76.0	24.0	81.3	18.7
OH-58	59.2	40.8	64.8	35.2
UH-1	46.3	53.7	46.5	53.5
AH-1	100.0	0.0	100.0	0.0
CH-47	31.5	68.5	46.9	53.1

TABLE 23. CASUALTY COSTS

INJURY SEVERITY	CREW	TROOP
FATALITY	$260,000	$ 79,000
MAJOR INJURY	221,000	121,000
MINOR INJURY	25,000	11,000

TABLE 24. AVERAGE INJURY COST PER ACCIDENT FOR BASELINE AND IMPROVED AIRCRAFT

Aircraft	OH-6		OH-58		UH-1		AH-1		CH-47	
% MIL-STD-1290	60	79	57	75	55	74	63	81	59	81
Airframe & Landing Gear	$100,580	$ 38,740	$ 75,718	$ 43,106	$172,689	$ 85,184	$ 58,614	$ 32,900	$ 40,419	$ 10,304
Seat & Restraint Systems	17,718	3,633	32,241	7,486	34,712	12,194	25,514	3,871	51,699	976
Internal Environment	38,411	27,959	79,103	51,322	77,893	49,831	37,329	22,000	44,322	34,815
Operational Problems (People)	30,815	21,022	3,378	3,378	3,513	1,779	11,100	7,029	51,699	39,433
Fire	28,662	0	47,384	0	34,439	0	37,143	0	60,451	0
Non-survivable Impact	22,293	22,293	84,615	84,615	70,444	70,444	122,571	122,571	172,797	173,797
TOTAL	$238,479	$113,647	$322,439	$189,907	$393,090	$219,432	$292,271	$188,371	$422,387	$259,335

TABLE 25. PERCENTAGE DISTRIBUTION OF STRIKES AND REPAIRABLE ACCIDENTS FOR BASELINE AND IMPROVED AIRCRAFT

Aircraft	Accident Rate	Strike %		Repair %	
		Baseline	Improved	Baseline	Improved
OH-6	36.40	34.6	24.1	63.6	75.9
OH-58	8.44	59.0	52.9	41.0	47.1
UH-1	10.38	47.6	34.9	52.4	65.1
AH-1	20.59	62.6	52.4	37.4	47.6
CH-47	6.53	80.2	52.8	19.8	47.2

2. Accidents involving postcrash fires were all strikes for the baseline aircraft, but the number of such would be reduced by 55% in the improved aircraft, due to crashworthy fuel systems (Reference 36).

3. The remaining baseline strikes were attributed to airframe (structure)/landing gear deficiencies, and these strikes would be reduced by the ratio of their improvement in PMSR.

Additional supporting data can be found in Appendix I.

As was stated previously, the accident cost accounting for strikes is simple and straightforward; strikes are charged at the acquisition cost of the aircraft. Table 26 shows the baseline aircraft acquisition costs, which were taken from Reference 37. The acquisition costs of the improved aircraft were estimated based on the crashworthiness improvements. Estimation of average repair costs for accidents which did not result in strikes was only slightly more difficult. Reference 38 yielded the maximum expenditure limits for aircraft repair, and these are displayed in the table for the baseline aircraft. It was assumed that the distribution of repairs was constant, that is there are as many aircraft repaired, for example at 25% of the maximum cost, as there are at 75% of the maximum cost. Therefore the average repair cost is halfway between zero and the maximum. These values then are displayed for the baseline aircraft in the table. Repair costs for the improved aircraft were estimated to take into account the higher acquisition cost of the improved aircraft, and the higher level of crashworthiness. Average repair costs for each aircraft were calculated as follows:

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36 SUMMARY OF U.S. ARMY CRASHWORTHY FUEL SYSTEMS ACCIDENT EXPERIENCE FROM APRIL 1970 TO 20 AUGUST 1974, U.S. Army Agency for Aviation Safety, Fort Rucker, Alabama, 36362, 1974

37 ARMY AVIATION PLANNING FACTORS, U.S. Army Field Manual FM 101-20, Department of the Army, Washington, D.C. 20310

38 MAINTENANCE EXPENDITURE LIMITS FOR ARMY AIRCRAFT, DOA Technical Bulletin TB-43-0002-3, Department of the Army, Washington, D.C. 20210

TABLE 26. ACQUISITION AND REPAIR COSTS FOR BASELINE AND IMPROVED AIRCRAFT

Aircraft	Baseline			Improved	
	Acquisition Cost	Maximum Expenditure Limit	Average Repair Cost	Acquisition Cost	Average Repair Cost
OH-6	$ 252,372	$ 132,748	$ 66,374	$ 283,472	$ 56,337
OH-58	288,398	118,820	59,410	319,443	49,879
UH-1	691,626	264,893	132,447	736,110	104,200
AH-1	1,022,623	269,561	148,281	1,074,509	120,796
CH-47	5,930,942	1,055,708	527,854	6,062,622	388,834

$$Cr_a = Cr_b \times \frac{Cai}{Ca_b} \times \frac{PMSRb}{PMSRi}$$

where
- Cr = repair cost
- Ca = acquisition cost
- $PMSR$ = Percentage of MIL-STD Rating
- a = average
- b = baseline
- i = improved

The results are shown in Table 26.

Total material damage cost per accident is calculated simply then as:

$$Cm_d = Ca \cdot ps + Cr \times pr$$

where
- ps = percentage of aircraft stricken
- pr = percentage of aircraft repaired

These costs were then distributed over the three causal factors for material damage, using the rationale previously described for the strike distribution, and assigning the repair costs to the airframe and landing gear category. The results are displayed in Table 27. As can be seen, the cost of non-survivable impact accidents increases slightly over the baseline, reflecting the higher acquisition cost of the improved aircraft that are stricken. The cost of postcrash fire strikes is reduced by about 51% on the average, based on the assumed 55% reduction in postcrash fires, and the higher acquisition cost of the aircraft stricken. Costs attributed to airframe and landing gear decrease in all cases except for the CH-47. This is due to the fact that the Chinook was estimated to have the largest decrease in the strike rate (and largest increase in repair rate). In other words, although the average repair cost decreased, the number of aircraft capable of being repaired after crashing increased even more.

Total average accident costs per accident are the sum of the injury costs in Table 24 and the material damage costs in Table 27. The results are illustrated in Table 28. Figure 36 is a plot of total average accident costs for all causal factors combined. The cost data is plotted against empty weight for three levels of crashworthiness. The baseline aircraft data is represented as the 60% line, the improved aircraft data is shown as the 80% line, and the 100% line is estimated from the other two. To use the figure, determine the aircraft empty weight and the PMSR,

TABLE 27. AVERAGE REPAIR COSTS FOR BASELINE AND IMPROVED AIRCRAFT

(Dollars)

Causal Factor	OH-6A		OH-58A		UH-1H		AH-1G		CH-47	
	60	79	57	75	55	74	63	81	59	81
Airframe & LG (Primary Struct.)	66,366	63,173	74,096	65,304	139,235	122,329	271,767	233,929	268,537	315,951
Fire	37,158	18,745	10,471	5,226	126,365	60,864	102,309	49,094	2,952,382	1,381,512
Non-survivable Impact	26,010	29,159	109,946	121 948	133,016	141,544	321,543	337,519	1,640,212	1,684,771
TOTAL	129,534	111,077	194,513	192,478	398,616	324,737	695,619	620,542	4,861,131	3,382,234

TABLE 28. TOTAL AVERAGE ACCIDENT COSTS FOR BASELINE AND IMPROVED AIRCRAFT

(Dollars)

Causal Factor	OH-6A		OH-58A		UH-1H		AH-1G		CH-47	
	60	79	57	75	55	74	63	81	59	81
Airframe & LG (Primary Struct.)	166,946	101,913	149,814	108,410	312,124	207,513	330,381	266,829	308,956	326,255
Seats & Restraint Systems	17,718	3,633	32,241	7,486	34,712	12,194	25,514	3,871	51,699	976
Internal Environment	38,411	27,959	79,103	51,322	77,893	49,831	37,329	22,000	44,322	34,815
Operational Problems	30,815	21,022	3,378	3,378	3,513	1,779	11,100	7,029	51,699	39,443
Fire	65,820	18,745	57,855	5,226	160,804	60,864	139,452	49,094	3,012,833	1,381,512
Non-survivable Impact	48,303	51,452	194,561	206,563	203,460	211,988	444,114	460,090	1,814,009	1,858,568
TOTAL	368,013	224,724	516,952	382,385	792,506	544,169	987,890	808,913	5,283,518	3,641,569

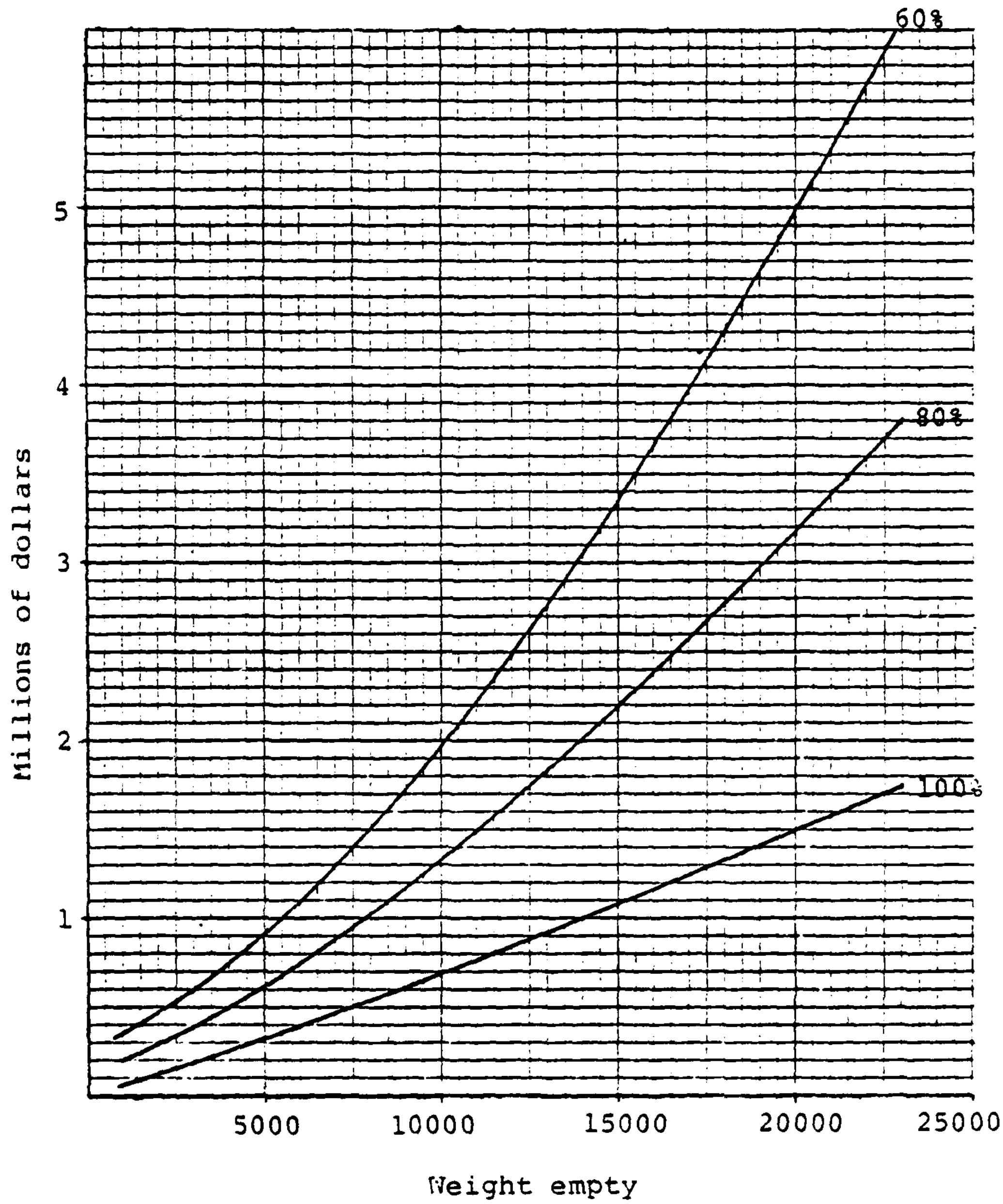

Figure 36. Total accident cost per aircraft as function of crashworthiness rating

then read off the average cost per accident. Then multiply this by the expected number of accidents over the life cycle.

Sensitivity Analyses

Two areas were examined to permit expanded use of the data developed in the study. The first was the subject of single vs. twin engines. As can be seen from the figures, the CH-47 data point is what pulls the curves upward and gives them their characteristic shape. The CH-47 is the only aircraft in the study with two engines. For practical purposes, aircraft with empty weight above about 7,500 pounds will be designed with twin engines. Therefore, when using the curves this fact should be kept in mind. For aircraft below 7,500 pounds, the curves can be used for twin-engine or single-engine aircraft by making the following adjustments. After calculating total CA feature acquisition cost, multiply by 1.345 to account for the cost of the additional engine. After computing total accident cost, multiply by 1.054 to account for the strike cost and repair cost increase of the additional engine. However, the number of accidents should be lower by almost 50% (Reference 39) for a twin-engine aircraft of the same design as a single engine aircraft.

The second area of interest was for aircraft with composite airframes. A similar approach was taken, and adjustment factors were developed which reflect a lower acquisition cost and assumed lower repair cost for composite airframes. After estimating the airframe acquisition cost from the curves, multiply by 0.87 for composites. After computing total accident cost, multiply by 0.982 for composites.

EXAMPLE OF THE USE OF THE DESIGN CURVES FOR WEIGHT PREDICTION

The design curves are meant for use by the designer in assessing the levels of crashworthiness achievable and consistent with the mean empty weight and gross weight of the aircraft.

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39 PROJECTED ACCIDENT COSTS FOR THE ADVANCED SCOUT HELICOPTER, USASC-TR80-1, U.S. Army Safety Center, Fort Rucker, Alabama, 36362, October 1979.

To be an acceptable design the aircraft must be able to perform its mission requirements. If the design curves show that an aircraft with a high level of crashworthiness has an excessive mean empty weight, then weight can be removed from the structure, landing gear, or seats to achieve the desired weight configuration by reducing the level of crashworthiness incorporated. This, of course, assumes that all other aircraft systems have been assessed and weight reductions achieved wherever possible.

To demonstrate the use of the weight curves the ACAP design, being studied concurrently with this program, will be used. This design was selected since it was developed as an independent study and estimated weight values were available for comparison with curve predictions.

An ADS-11 assessment, similar to those performed for the baseline aircraft, was completed and showed the aircraft to be 85 percent of the MIL-STD-1290 (AV) requirements. This analysis is included in Appendix G.

The design curves presented in Figures 25, 26, 27, 28, 29 and 30 were used to predict the weight values associated with crashworthiness features. The mean empty weight estimated for the ACAP using the more conventional weight estimating techniques was used as the input value to the design curves in conjunction with the 85 percent of MIL-STD-1290 rating.

A comparison of predicted weight values from the design curves and actual weight estimates for the metallic and composite aircraft are presented in Table 29. All of the predicted values were obtained from the design curves assuming an 85 percent MIL-STD-1290 (AV) rating and a mean empty weight as estimated by the weights engineer for each of the designs. All predicted values show good agreement with the estimated weight values for the actual designs except in the case of the metallic ACAP, where the predicted gross weight of 7000 pounds exceeds the estimated value by 17 percent. This indicates that the metallic aircraft does not conform to the average mission for that size of aircraft but will be limited in its payload capability and/or fuel content and subsequent overall mission capability.

In addition, the fuel system weight prediction exceeded the design estimate by more than 30 percent. When discussing Figure 27 previously, it was noted that design features can cause variations from the average installation.

TABLE 29. COMPARISON BETWEEN PREDICTED AND ESTIMATED WEIGHT VALUES FOR THE METALLIC AND COMPOSITE ACAP CONCEPTS

ELEMENT	METALLIC ACAP		COMPOSITE ACAP	
	PREDICTED WEIGHT (LB)	ESTIMATED WEIGHT (LB)	PREDICTED WEIGHT (LB)	ESTIMATED WEIGHT (LB)
GROSS WEIGHT	7000	5997	6000	5997
MEAN EMPTY WEIGHT	4055	4055	3810	3810
STRUCTURE	810	842	650	667
LANDING GEAR	180	188	180	188
SEATS (2 CREW + 2 TROOP)	272*	280	272*	276

NOTE: THE PREDICTED VALUES ARE FOR AN AIRCRAFT WITH AN 85 PERCENT MIL-STD-1290 (AV) RATING AND A MEAN EMPTY WEIGHT AS ESTIMATED.

*43 POUNDS ADDED PER CREW SEAT FOR ARMORED BUCKET

Such is the case with the ACAP design, where a single fuel tank is mounted close to the engines, thus explaining the lower weight estimate.

To demonstrate the use of the design curves, Figures 37 and 38 indicate the ACAP design point defined by the mean empty weight and the percentage of MIL-STD-1290 rating. The corresponding gross weight and airframe weight values are read directly from the curves, these being the values in Table 29.

It should be noted that this single demonstration does not validate the procedure for any aircraft design but does show that reasonable estimates are possible using average data for typical aircraft designs.

Cost assessments have not been demonstrated here but the required values can readily be extracted from the relevant curves once the weight values have been determined. An example is in the subsequent section on the design of a Scout helicopter.

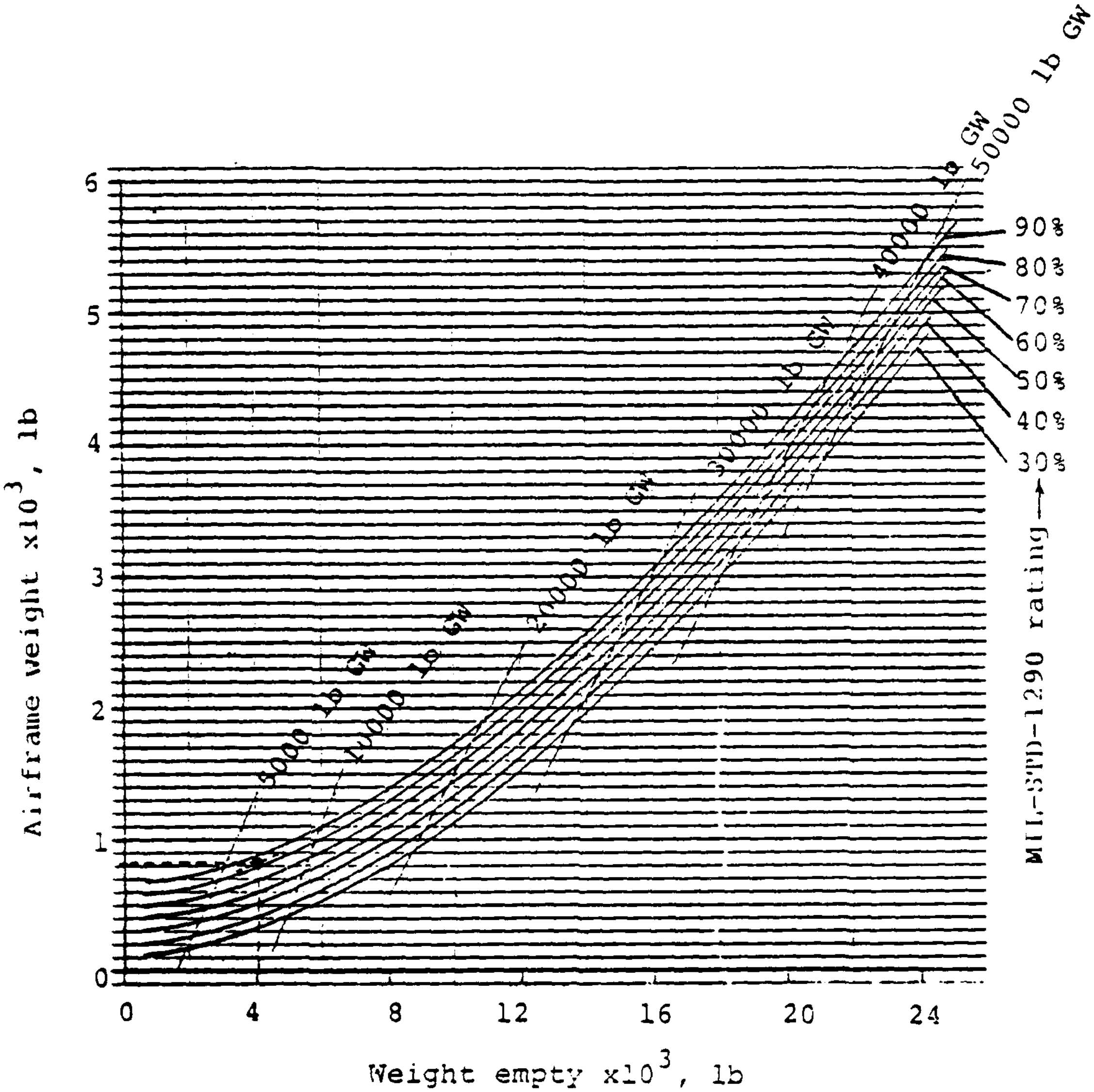


Figure 37. Airframe weight estimation for ACAP with metallic structure

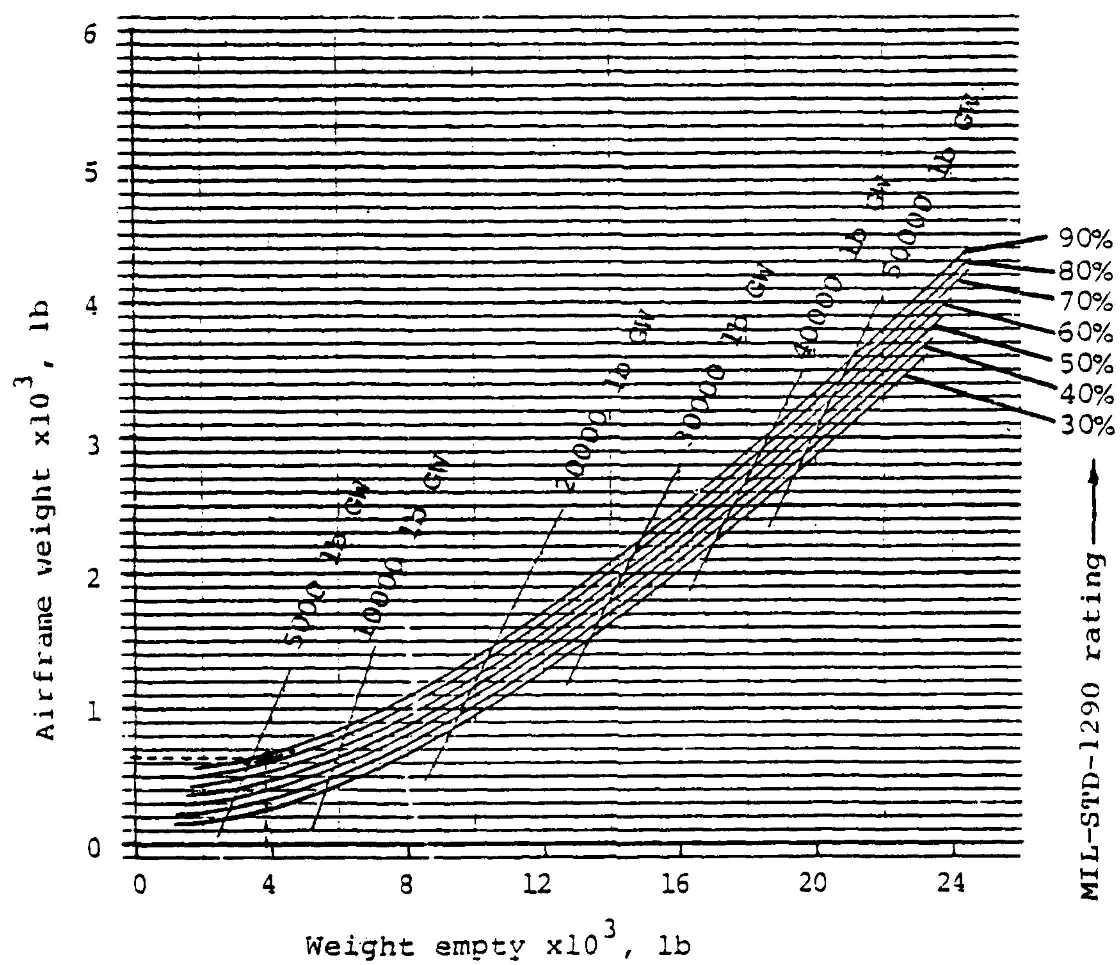


Figure 38. Airframe weight estimation for ACAP with composite structure

SCOUT HELICOPTER CRASHWORTHINESS ANALYSIS

To further demonstrate the use of the design curves generated during this study, two Scout Helicopter designs were produced, one having its primary structure made from metallic materials and the other from composites.

The requirement was to define a future Scout helicopter which had a mission gross weight of less than 10,000 pounds and which was equipped with TADS/PNVS visionics systems and a mast-mounted sight installation.

The designs were required to provide optimum crash protection to the crew and to the expensive TADS/PNVS equipment.

DEFINITION OF SCOUT CONCEPTS

A mission profile for a Scout, or ASH, mission was used as the basis for the aircraft definition together with weight estimates for onboard equipment, crew and crashworthy elements of the design. Table 30 shows the mission profile used for this study and Table 31 presents the summary weight statements used.

A HESCOMP analysis, "Helicopter Sizing, and Performance Computer Program" was performed assuming a twin-engine configuration to provide the power and efficiencies consistent with the mission requirements. HESCOMP was originally developed by the Boeing Vertol Company under contract to NASA (NAS2-6107) and was revised under U.S. Navy contracts N62269-74-C-0757 and N62269-79-C-0217. The final documentation was published as the second revision of Boeing Vertol report D210-10699-2 (Reference 40).

To allow a reasonable assessment of the validity of the design curves generated under this contract, several Scout designs were performed to accommodate variations in aircraft geometry and density altitude design points. Table 32 summarizes the geometrical and performance data for these designs for both metallic and composite airframes.

The analyses assumed that 834 pounds of avionics/visionics equipment were installed, and other payload including the two crew amounted to 521 pounds. Two rubberized engines

[40] USER'S MANUAL FOR HESCOMP, THE HELICOPTER SIZING AND PERFORMANCE COMPUTER PROGRAM, D210-10699-2, Boeing Vertol Company, P.O. Box 16858, Philadelphia, Pennsylvania, 19142, October 1979

TABLE 30. MISSION PROFILE FOR "SCOUT"
(59°F @ SEA LEVEL)

FLIGHT CONDITION	TIME (MIN.)
HOGE	4
CRUISE @ 120 KTAS	7
HOGE	8
CRUISE @ 60 KTAS	9
HOGE	30
CRUISE @ 20 KTAS	17
HOGE	10
CRUISE @ 30 KTAS	5
HOGE	15
CRUISE @ 40 KTAS	6
CRUISE @ 60 KTAS	9
RES. CRUISE @ 130 KTAS	30
TOTAL ENDURANCE	150 (2.5 HRS.)

TABLE 31. SUMMARY WEIGHT STATEMENTS FOR METALLIC AND COMPOSITE "SCOUT"

	WEIGHT SUMMARY - PRELIMINARY DESIGN				
	METALLIC 4000 ft./95°F, D = 36.6 ft.		COMPOSITE 4000 ft./95°F, D = 36.6 ft.		
WING					
ROTOR	525		492		
TAIL	59		44		
SURFACES		36		23	
ROTOR		23		21	
BODY	928		708		
BASIC					
SECONDARY					
ALIGHTING GEAR GROUP	189		174		
ENGINE SECTION	90		52		
PROPULSION GROUP	966		908		
ENGINE		373		353	
EXHAUST SYSTEM					
COOLING					
ENGINE INSTL		52		49	
STARTING					
LUBRICATING					
FUEL		153		138	
DRIVE		388		368	
FLIGHT CONTROLS	332		321		
AUX. POWER PLANT					
INSTRUMENTS	56		56		
HYDR. & PNEUMATIC					
ELECTRICAL GROUP	210		210		INCL. BELOW
AVIONICS GROUP					
ARMAMENT GROUP					
FURN. & EQUIP. GROUP	358		358		
ACCOM. FOR PERSON		276		276	INCL. 43 LB. PER
MISC. EQUIPMENT		33		33	SEAT FOR
FURNISHINGS		20		20	ARMORED BUCKET.
EMERG. EQUIPMENT		29		29	
AIR CONDITIONING	33		33		
ANTI-ICING GROUP	3		3		
LOAD AND HANDLING GP.	5		5		
VIBRATION REDUCTION	75		75		
WEIGHT EMPTY	3829		3439		
CREW					
TRAPPED LIQUIDS					
ENGINE OIL					
F.U.L.	521		521		
AVIONICS - VISIONICS	834		834		
FUEL	901		814		
GROSS WEIGHT	6085		5607		

TABLE 32. HESCOMP ANALYSIS RESULTS FOR COMPOSITE AND METALLIC DESIGNS

	METALLIC "SCOUT" (36.6 FT. DMR)				COMPOSITE "SCOUT" (36.6 FT. DMR)				ALTERNATE COMPOSITE "SCOUT" (8 LB/FT.^{2} DISC LOADING AND 700 FT./SEC. ROTOR TIP SPEED)			
DESIGN AMBIENT												
• ALTITUDE (FT.)	2000	2000	3000	4000	2000	2000	3000	4000	2000	2000	3000	4000
• TEMPERATURE (^oF)	70	95	95	95	70	95	95	95	70	95	95	95
ROTOR GEOMETRY												
• DMR (FT.)	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	28.8	29.7	29.9	30.2
• σ MR	0.059	0.065	0.069	0.072	0.055	0.060	0.063	0.067	0.089	0.093	0.096	0.100
• DTR (FT.)	6.4	6.5	6.5	6.5	6.3	6.4	6.4	6.4	5.8	6.0	6.0	6.0
• σ TR	0.126	0.139	0.148	0.157	0.119	0.132	0.139	0.148	0.166	0.176	0.186	0.196
WEIGHT (LB.)												
• GROSS	5597	5905	5[illegible]83	6085	5175	5464	5533	5607	5217	5553	5633	5726
• FUEL	758	839	864	901	689	769	790	814	822	920	944	970
• EMPTY	3484	3710	3764	3829	3131	3340	3387	3439	3040	3278	3333	3401
• STRUCTURE	896	916	921	928	685	701	704	708	652	673	678	684
AIRSPEED CAPABILITY @ 4000 FT./95°F												
V_{MRP} (KTAS)	130.0	146.0	148.0	150.1	130.6	146.2	148.1	150.1	127.0	145.4	147.6	150.8
POWER (HP)												
• TOTAL ENGINE AT SL/59°F	912	1195	1244	1303	851	1113	1157	1205	938	1233	1286	1358
• TRANSMISSION LIMIT	787	1030	1073	1124	734	960	998	1039	809	1063	1109	1171

based on the Allison 280-C1 scaleable engine were used and the transmission limit was rated at 86 percent total engine installed power at sea-level/59°F.

Figure 39 is a general arrangement drawing of a typical Scout design based on the HESCOMP analyses. The basic contents of the aircraft are the two crew members, the TADS/PNVS and the avionics and visionics equipment. All of these were required to be protected to minimize damage when subjected to a crash environment as defined in Reference 1.

The maximum level of protection was incorporated into the designs to minimize 'G' levels for both the occupants and critical equipment installations and the probability of postcrash fire.

Figures 40 and 41 show the crashworthiness features incorporated into the designs for a metallic and composite airframe respectively. It was assumed that the structure was the only variable in these designs, all other systems being common to each.

Noteworthy features of each design with respect to crashworthiness are:

- Vertical impact protection is provided by a 20 ft/sec landing gear acting in series with a deep underfloor structure for the expensive avionics/visionics with the addition of stroking seats for occupants.
- Landing gear is designed for 20 ft/sec vertical impact without ground contact and 42 ft/sec without failure of gear or attachments.
- Longitudinal impact protection is provided by a relatively long nose structure projecting forward of the crew pedal location together with an anti-nose-plowing canted structural bulkhead.
- Large mass retention and minimization of fuselage crushing is attained by using reinforced frames, longitudinal members and bulkheads at the required locations. Extension of the longitudinal members also contributed in the provision of blade impact protection and rollover integrity.
- All mass items including the mast-mounted sight are designed to the 20, 20, 18g retention requirements.

- The fuel system is installed away from areas where damage may occur and/or ignition sources prevail. The fuel cell is located in an area where penetration is unlikely and the surrounding structure is arranged to provide protection against effects of hydraulic ram. Lines are kept short and a suction fuel system is used.

- The avionics/visionics bay located forward of the fuel cell is protected from mass penetration by the overhead structure and against excessive vertical 'G' loads by the deep underfloor structure.

- The crew seats are energy attenuating in the vertical direction and employ a three-level attenuator setting to accommodate a wide range of occupant weights while keeping the seat stroke to a maximum of 7 inches. Such an installation precludes the need for a floor well in which to stroke, thus maintaining a good underfloor stroking depth; it also allows a low crown profile which assists in reducing the overall height of the aircraft with the associated performance improvements. A five-point harness system provides adequate restraint to minimize occupant motions for longitudinal and lateral acceleration environments.

Discussion of Design Features

The aircraft layout, as shown in Figure 39, was developed to optimize the incorporation of desirable design features.

The four-bladed rotor system was selected to keep the diameter relatively small and to reduce the vibration environment in the cabin area. Reduction in blade diameter also allows a smaller aircraft profile with a resultant lower visual signature.

The tail wheel landing gear configuration was selected to minimize crash resistance with respect to the main gear location. The main gear is situated away from the fuel cell where failure will likely preclude cabin penetration. In addition the nose area is unencumbered, thus allowing the incorporation of good longitudinal attenuation and anti-nose plowing structural features. The tail wheel configuration makes full use of the tail boom strength dictated by ballistic tolerance requirements, which were assumed to be relevant for these designs, and it eliminated the need for a tail bumper, which is required for nose-wheeled aircraft.

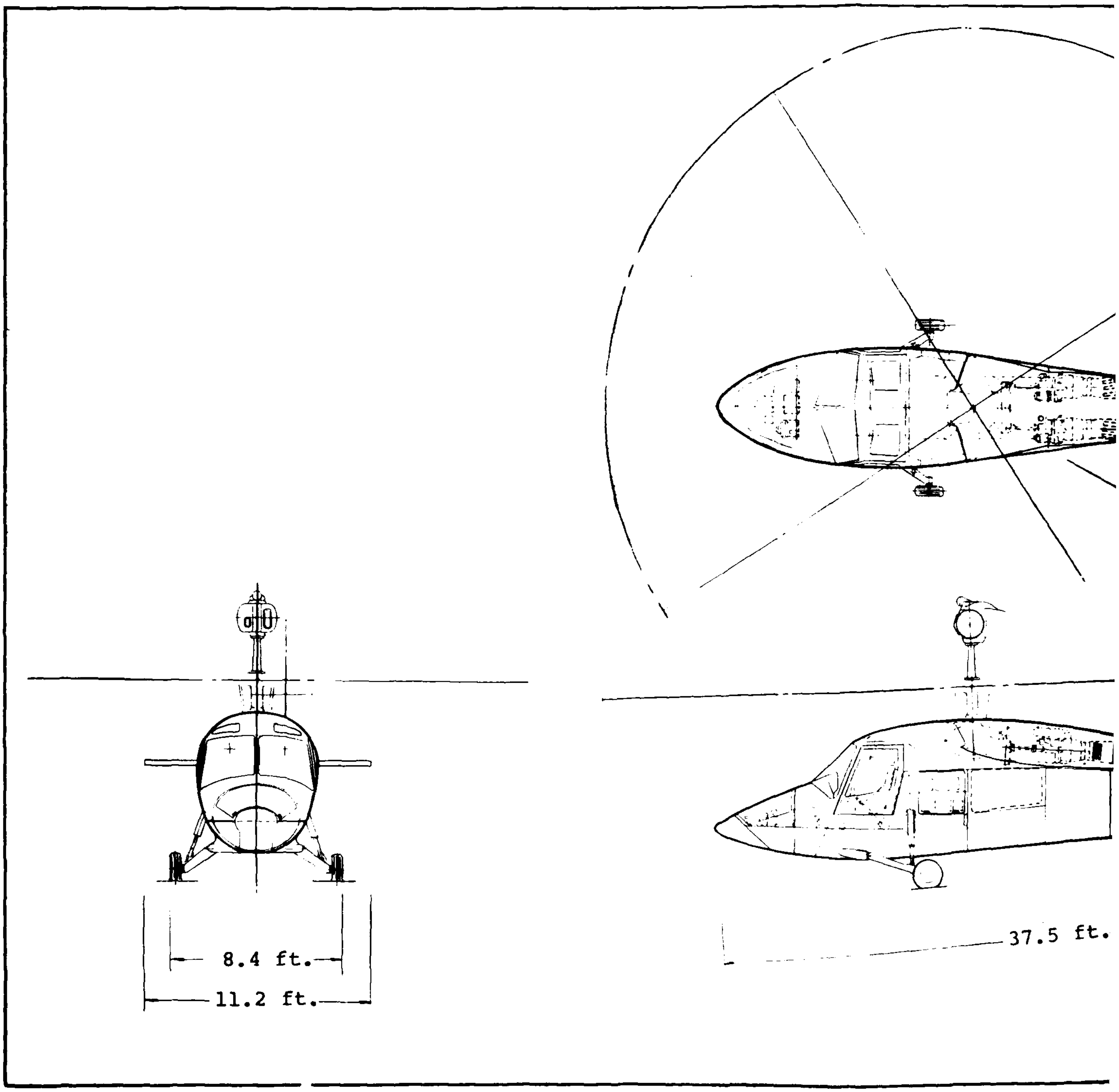
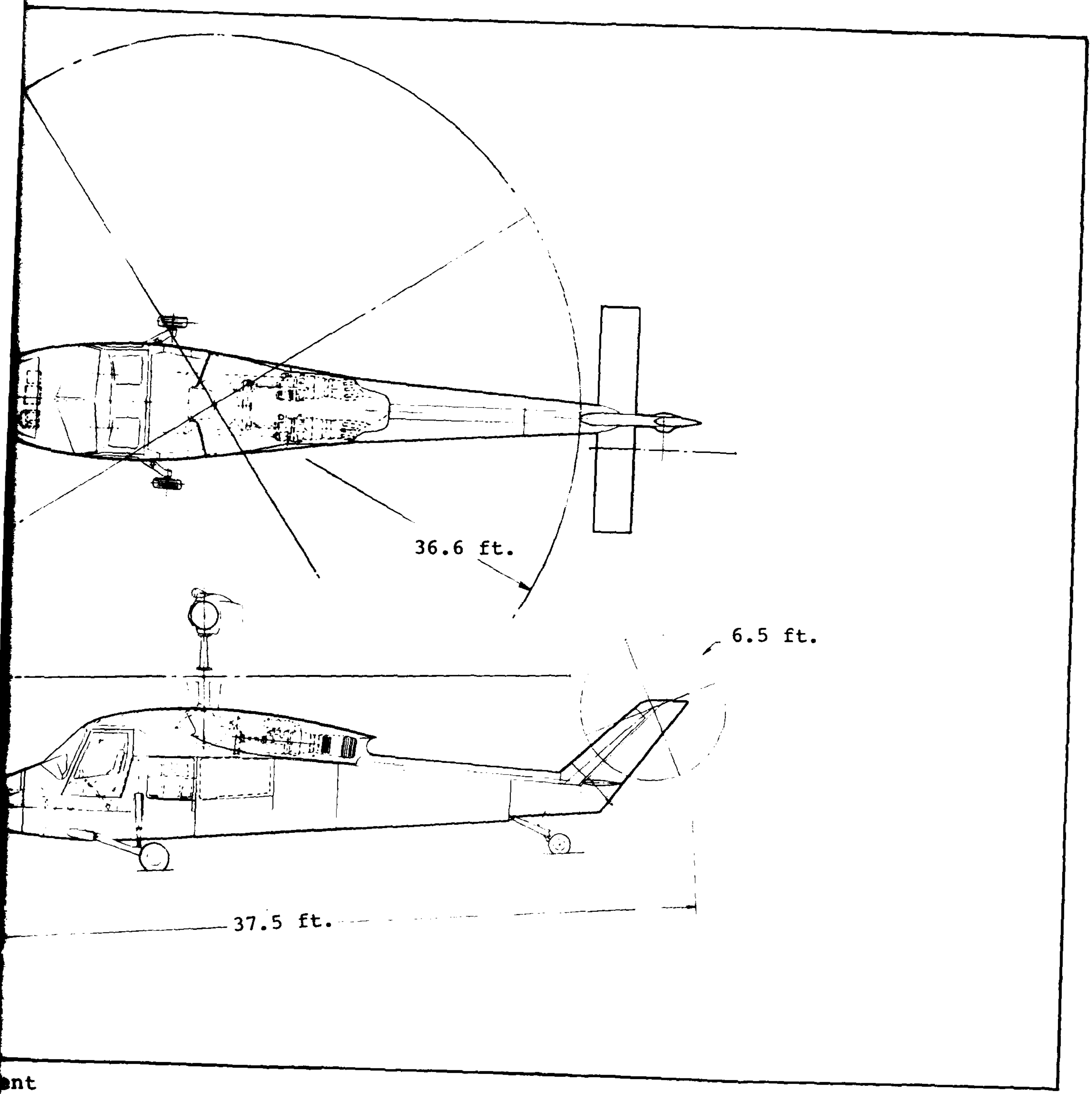


Figure 39. "Scout" helicopter design - general arrangement



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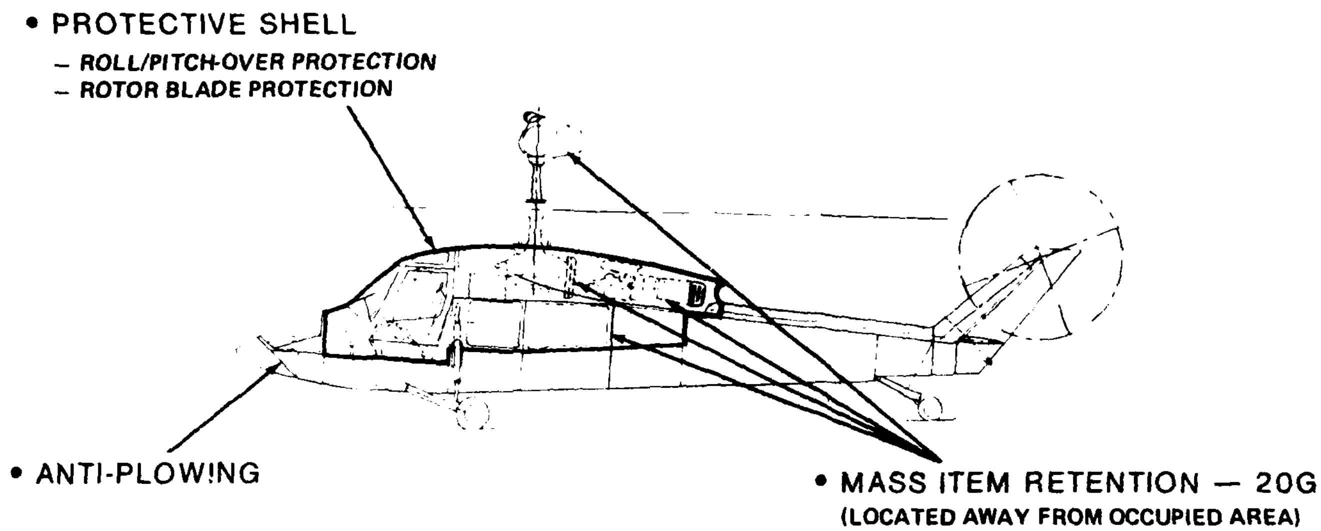
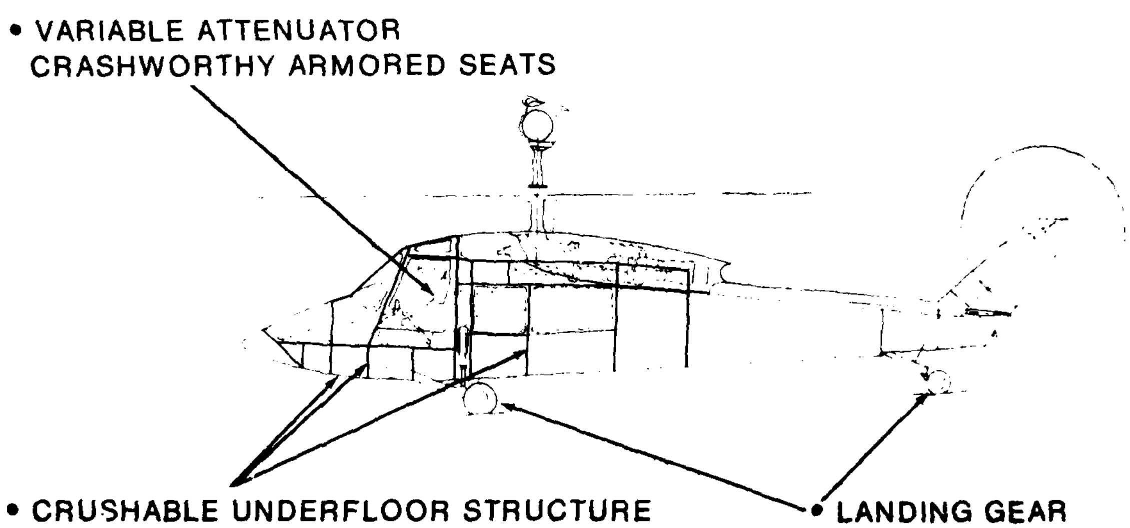
PERSONNEL AND HIGH-VALUE MISSION EQUIPMENT SPACE RETENTION



ENERGY ATTENUATION



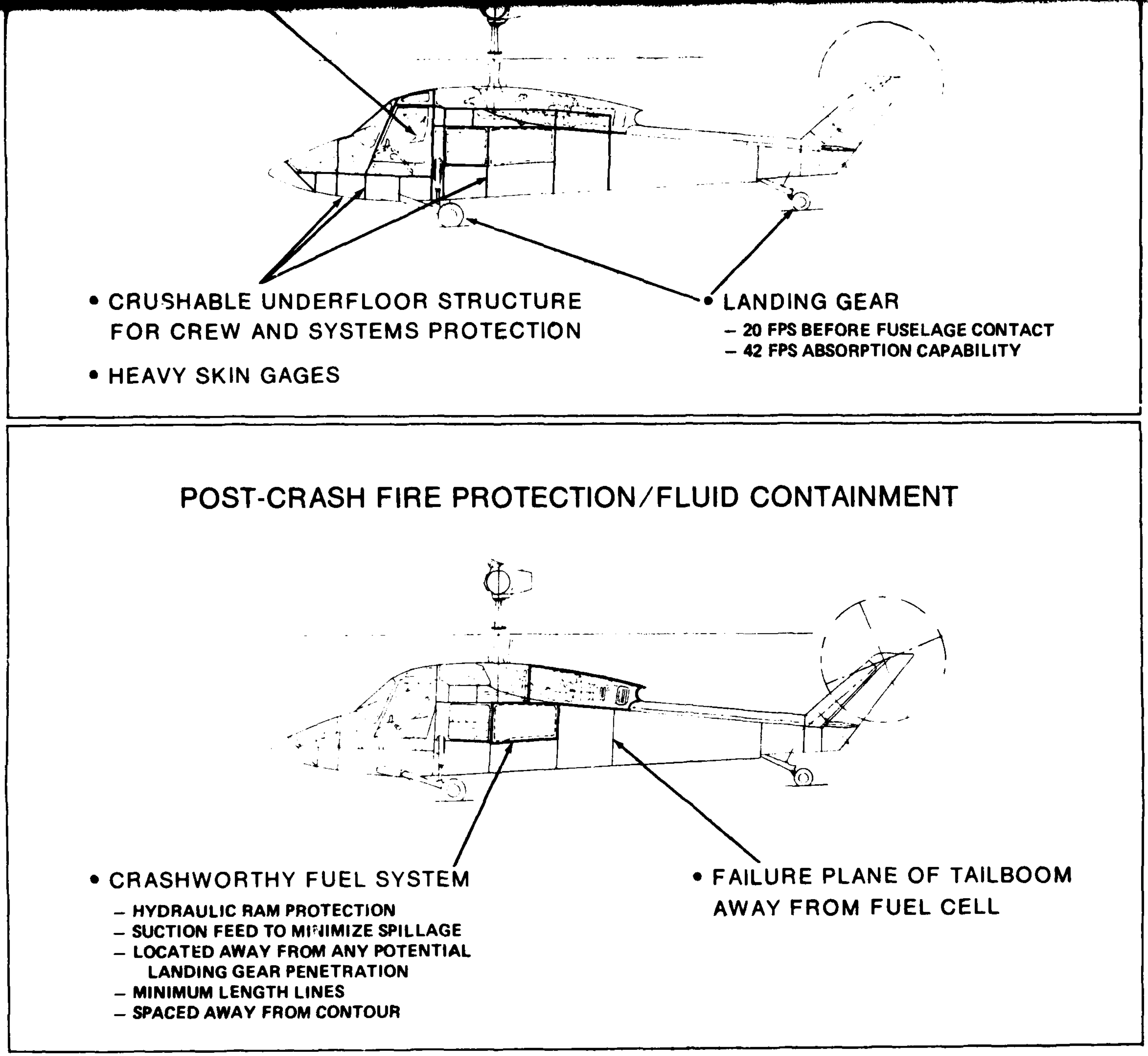
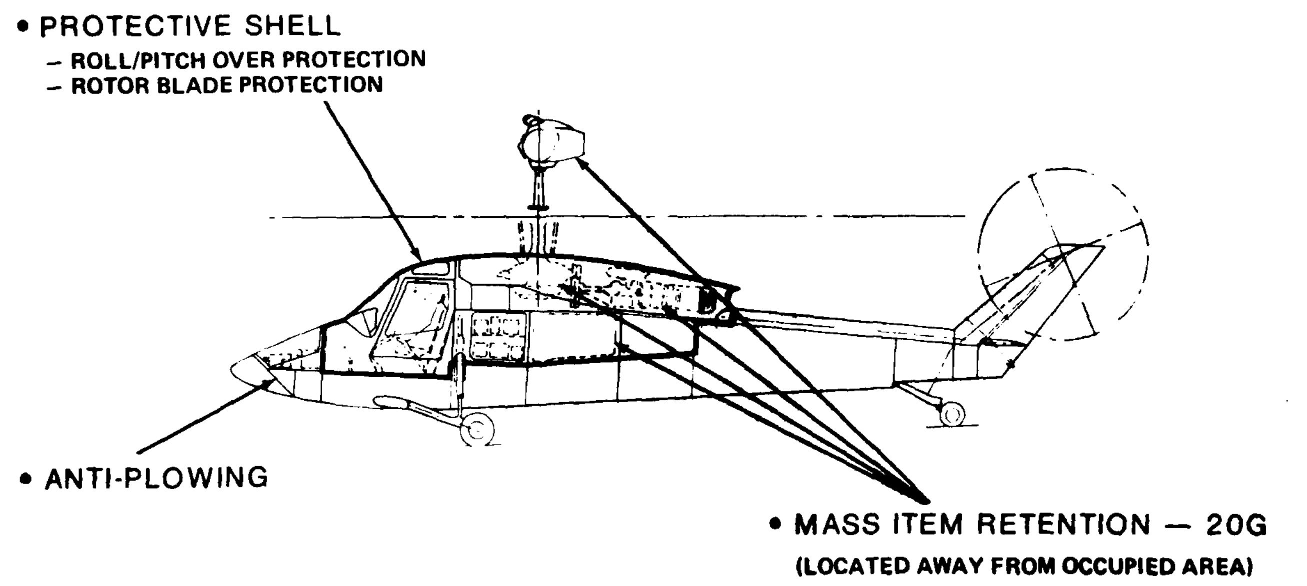
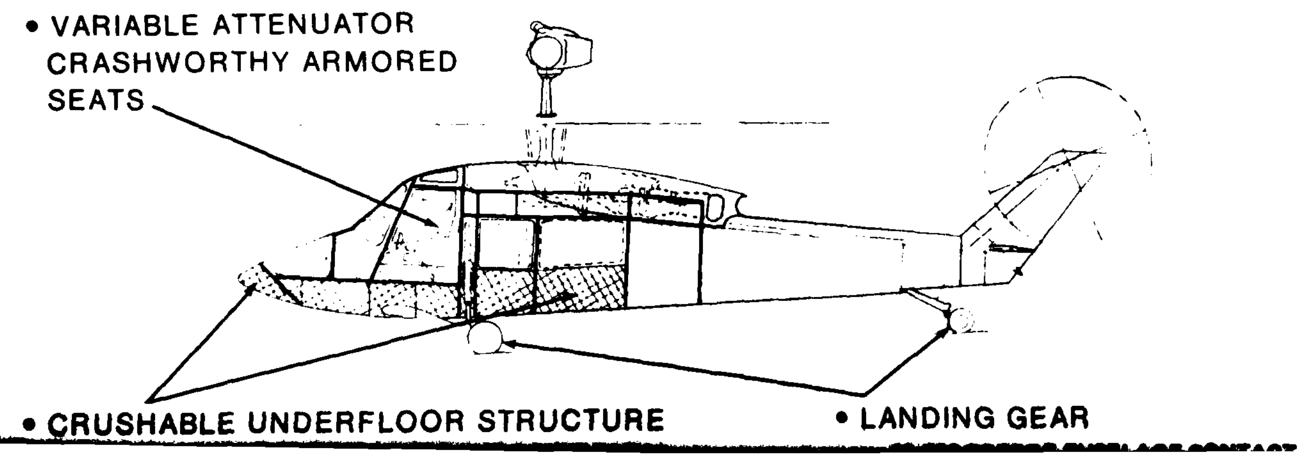


Figure 40. Crashworthiness features for "Scout" with metallic airframe

PERSONNEL AND HIGH VALUE MISSION EQUIPMENT SPACE RETENTION



ENERGY ATTENUATION



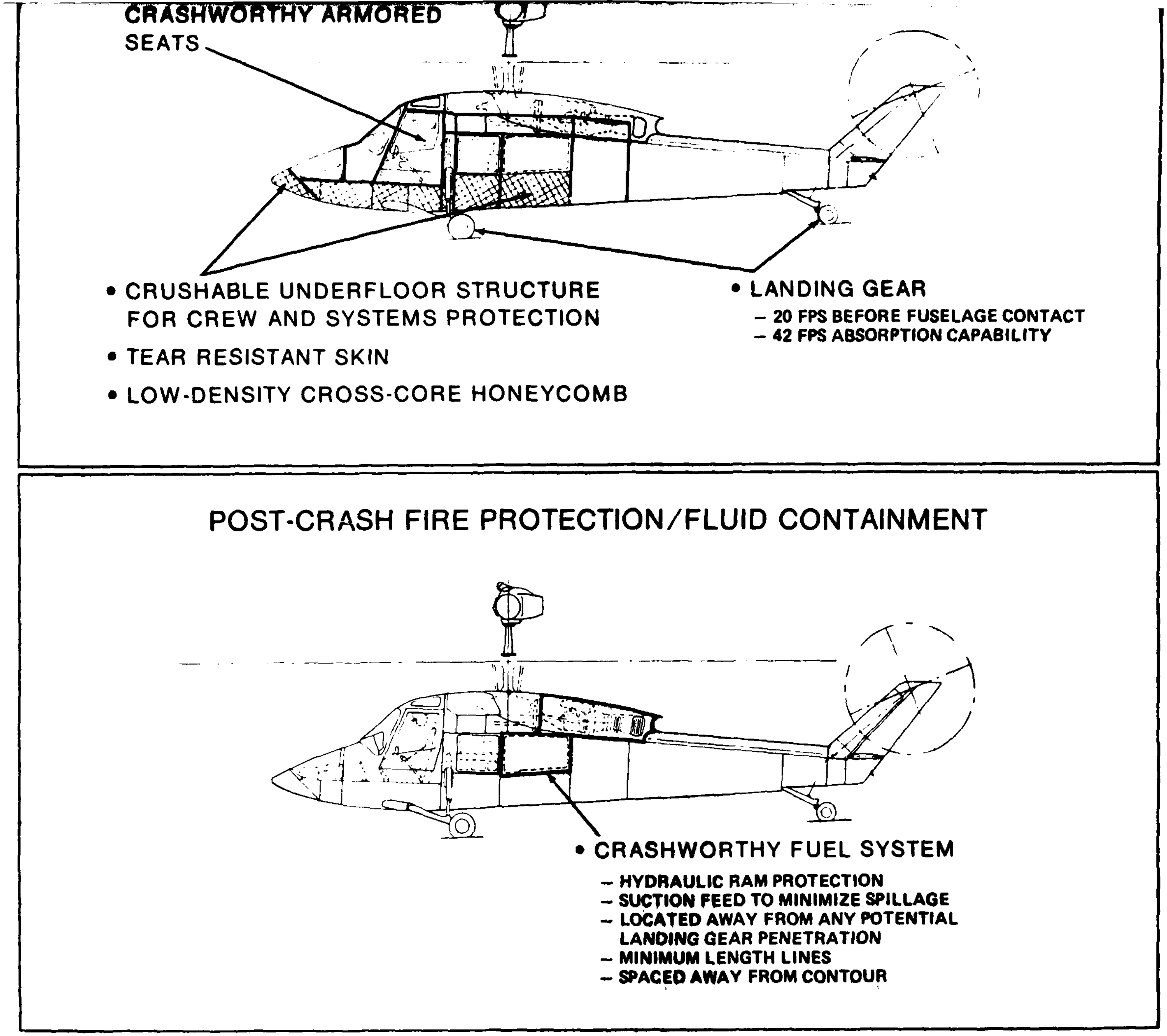


Figure 41. Crashworthiness features for "Scout" with composite airframe

The TADS/PNVS and avionics equipment installation provides optimum crash impact protection and also allows easy access for maintenance with the two-bay concept with doors on each side of the aircraft.

It should be noted that the aircraft can be produced as a passenger-carrying vehicle by removing the avionics bays and lengthening the fuselage aft of the cockpit. This would then be an aircraft similar in capacity to the OH-6 and OH-58.

Although not included as part of this study, it was assumed that all systems will comply to relevant specifications and be installed to minimize maintenance requirements and be consistent with optimum occupant protection in a crash environment. For example, fuel system elements will have self-sealing breakaway fitting, minimum lengths and a suction feed system. This will minimize leakage potential and, in conjunction with its segregation from potential ignition sources, will minimize the probability of fire casualties. Control system rods will be routed under the cockpit floor between the seats to minimize their effects on occupant 'G' levels in a vertical impact, then pass vertically aft of the crew area to the upper controls.

Details of Design Features using Composite Materials

The metallic design was assumed to incorporate standard materials and design techniques and will not be discussed in this report. To allow the reader insight into the types of structure possible using composite materials, and some of the problems that must be considered, a summary of typical design concepts developed for the Advanced Composite Airframe Program (ACAP) is presented in Figures 42 and 43. Figure 42 shows a typical design employing a halfshell concept with integral structural members. Typical structural details are shown for frames, joints and the clamshell centerline joint.

Figure 43 presents other methods of construction for comparison with the honeycomb clamshell. In addition, an alternative filament-wound isogrid tail boom structure is shown. This provides protection against ballistic strikes and can be designed to safely carry flight loads after impact by any threat up to the 23mm HEI.

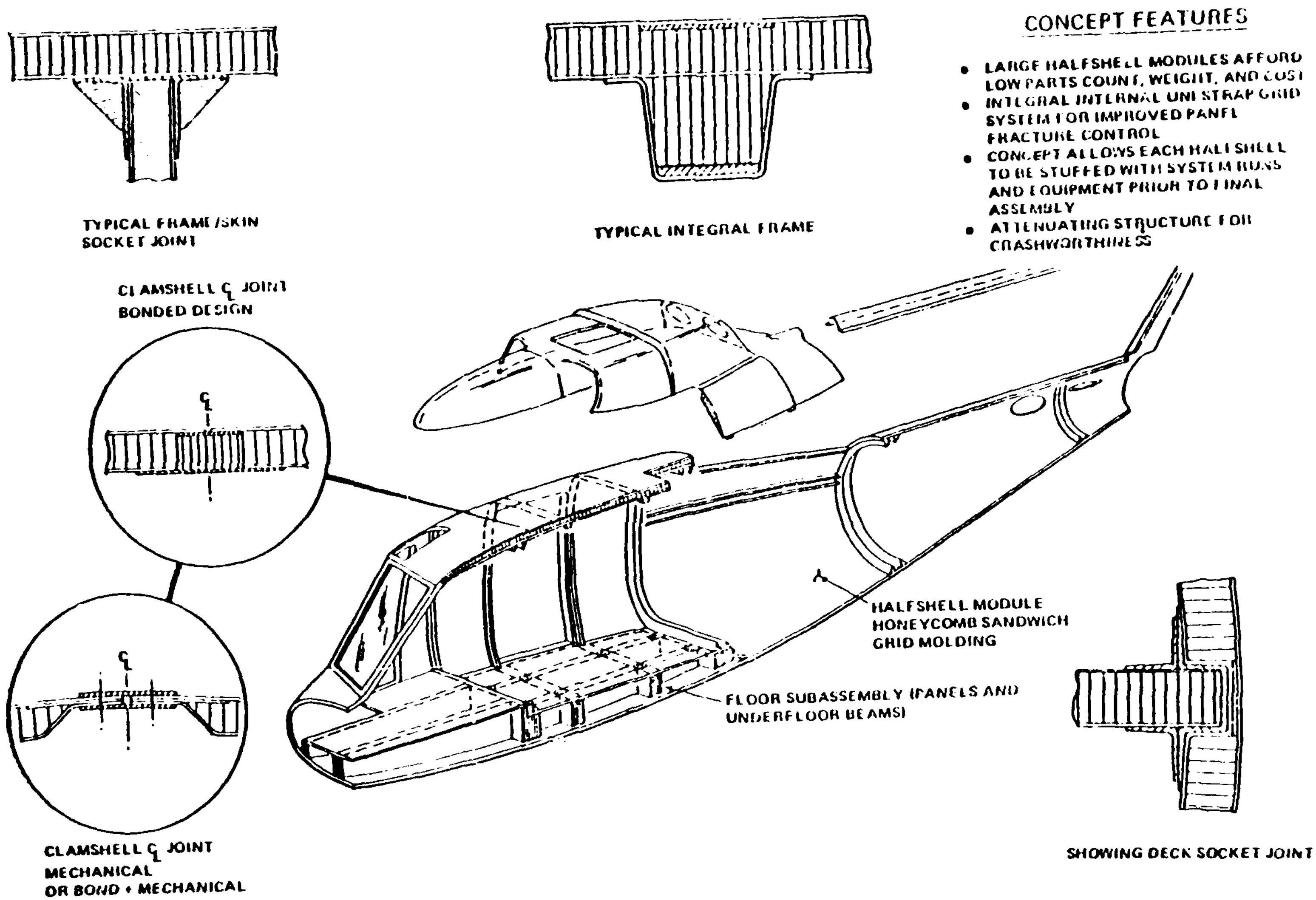


Figure 42. Typical ACAP construction using composite clamshell technique

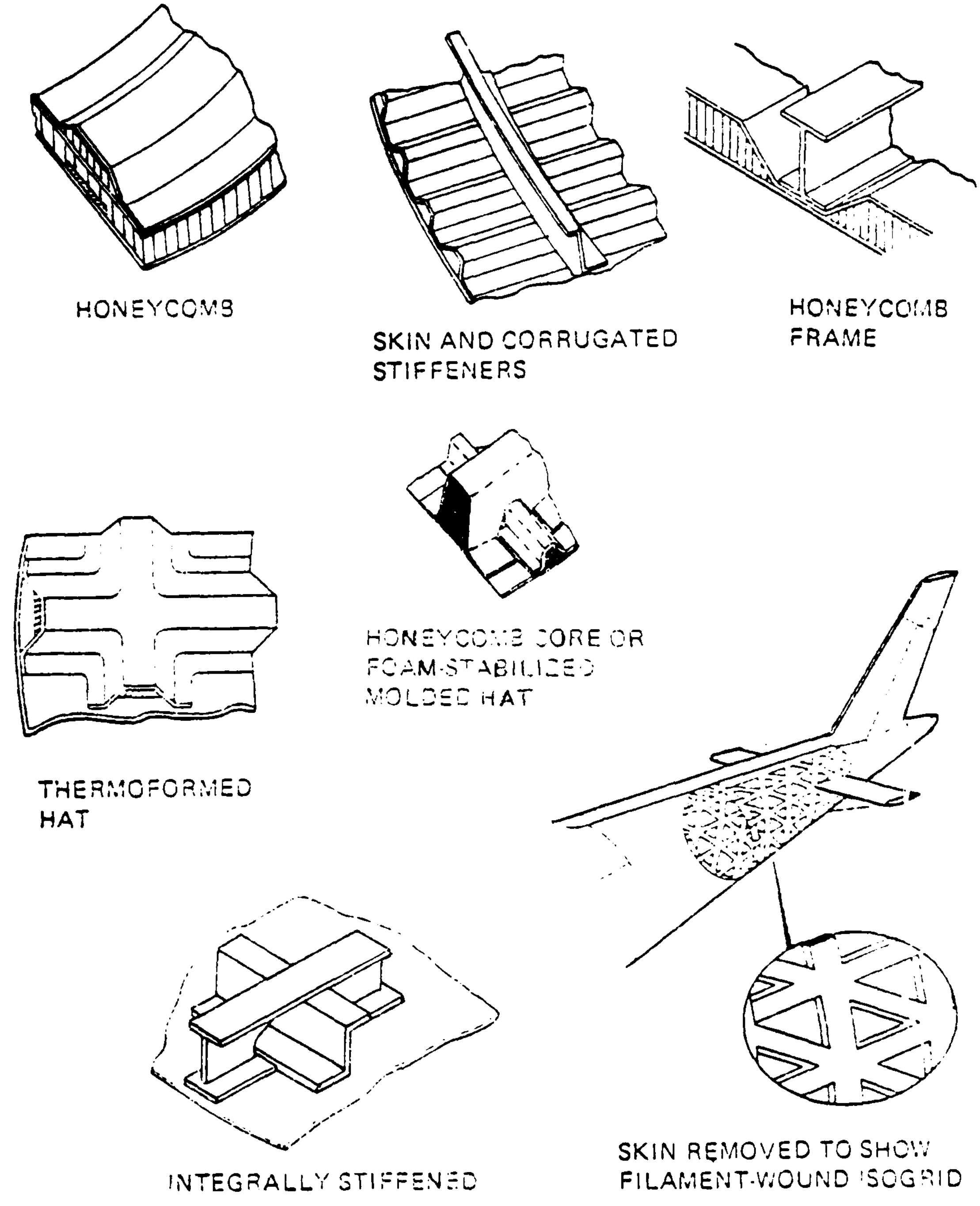


Figure 43. Other construction methods considered for composite ACAP

CRASHWORTHINESS ASSESSMENT

A detailed crashworthiness analysis of the airframe is not consistent with the scope of this program. Estimates have been made to ensure adequate stroking distances for longitudinal and vertical impacts to offer the required level of protection to both human occupants and expensive avionics and visionics equipment.

Figure 39 shows the structural arrangement; dimensions from this illustration were used for a simplified analysis. In all instances it was assumed that if adequate stroking distance was provided by the series combination of landing gear, structure and seat, structural designs were possible based on past experience with the design and testing of aircraft to meet the requirements of Reference 1.

In addition, an ADS-11 (Reference 30) analysis was performed to obtain a percentage level of crashworthiness. This analysis was completed by subjectively applying the requirements of MIL-STD-1290 (AV) to define the scores for each element of the ADS-11 analysis. The results of this analysis are presented in Appendix H, and the overall crashworthiness score achieved was 94 percent of a MIL-STD-1290 rating.

Vertical Impact

The specified requirements are:

- no fuselage contact at 20 ft/sec impact
- occupant survival and minimal injuries at 42 ft/sec impact velocity.

The landing gear is sized to absorb the total aircraft energy at 20 ft/sec. For an impact at 42 ft/sec the gear decelerates the aircraft to 36.93 ft/sec after absorbing the same amount of energy prior to fuselage contact.

$$\text{i.e., Fuselage impact velocity} = (42^2 - 20^2)^{1/2}$$

$$= \underline{36.93 \text{ ft/sec}}$$

If conservatively it is assumed that the gear does not absorb any more energy and also that a rotor lift of 1xW prevails, thus cancelling potential energy effects, the acceleration levels for occupants and avionics bay are as follows:

Depth of structure under seat = 18 inches

Assuming a 60% structural dynamic efficiency the maximum 'G' level at the cockpit floor for a triangular pulse =

$$\frac{36.93^2}{2 \times 32.2 \times 1.5} \times \frac{1}{0.6} \times 2$$

$$= \underline{47.1g}.$$

This value is comparable with the seat design specification which requires a triangular pulse peak acceleration of 48g when measured at the cockpit floor. Thus, the incorporation of a crashworthy stroking seat designed to satisfy MIL-STD- 1290 (AV) (Reference 1) and TR79-22 (Reference 2) will provide adequate occupant protection.

In the avionics bay area the underfloor structure depth is 24 inches, and this results in a 35.3 g level at the floor of the bay. This value is regarded as a maximum since other structural deformation and deflections will occur to attenuate the energy levels experienced by hardware mounted above the floor level; this includes the mast-mounted sight assembly. From experience with previous designs and tests it has been demonstrated that an aircraft designed to satisfy stiffness, fatigue and large mass retention criteria retains masses under transient 'G' conditions at high acceleration levels. Values in excess of 80g have been measured during controlled testing for mass items such as transmissions without yielding of the support members. Thus the above transient value of no greater than 35.3 g is regarded as acceptable for the design.

The 42-ft/sec impact at a 30° roll angle is much more difficult to analyze. The landing gear is only sized for symmetrical impacts and under such conditions will allow fuselage contact at a greater velocity than 36.93 ft/sec. The softness of the ground impacted, whether the gear fails or not, the roll inertia of the aircraft, and the energy content of the rotor systems will determine the rotational response of the aircraft after impact. Rotation to a symmetrical impact condition may occur but, on the other hand, a combination of circumstances may result in landing gear failure, local fuselage crushing, and possibly rollover.

The design, as presented, has a wide track main landing gear with an angle from the vertical of approximately 55 degrees. This was done to provide better stability for rolled and lateral impacts. However, with the high center

of gravity due to the mast mounted sight installation, rollover under such conditions is a possibility.

Longitudinal Impact

Using a similar approach to that used for the vertical impact condition, analysis of 40-ft/sec impact with a rigid abutment yields the following:

Structure depth forward of the cockpit pedals = 48 inches.

Assuming a triangular pulse and 60 percent structural dynamic efficiency

$$G_{40} = \frac{40^2 \times 2}{2 \times 32.2 \times 4 \times 0.6}$$

$$= 20.7g$$

This value is within human tolerance limits for a well-restrained seated occupant.

Lateral Impact

Lateral impact protection at a velocity of 30 feet per second is more difficult to achieve than vertical and longitudinal protection. Space limitations in the cockpit do not allow a desirable distance between an occupant and sidewall to satisfy the 15-percent volume reduction specified in Reference 1. To alleviate this problem the crew are well helmeted and restrained in seats which may be equipped with armor wings. These features offer protection should the side of the fuselage fail inwards. To minimize this the design, as shown in Figure 39, has a fuselage section that is basically elliptical. Such a section can provide high load resistance without buckling due to direct compressive loads building up in the fuselage shell.

Rollover and Blade Penetration Protection

The structure as it evolved for the other levels of protection discussed previously and for large mass retention offers sufficient rollover and blade penetration resistance. The elliptical shape is excellent both from the load carrying viewpoint and because it does not cause abrupt changes in roll resistance.

Overhead structure, the longitudinal beams and frame members, offers blade penetration protection when integrated with the cockpit overhead structure as shown in Figures 40 and 41.

Postcrash Fire Prevention

All fuel system components will meet the requirements of MIL-STD-1290 (AV) (Reference 1) and TR 79-22 (Reference 2) with respect to hardware and to their installation relative to potential for cell penetration and the proximity of ignition sources, be they electrical or engine related.

Hydraulic and lubricating oils, which represent a potential fire hazard, will be located away from potential ignition sources; and the electrical system will be installed to minimize wiring failures and breakaway of items such as the battery.

Emergency Egress

With only a two-man crew the emergency egress requirements are easily met, even with the aircraft in a rolled post-crash attitude. Both cockpit doors are emergency exits, by definition, and will include an emergency release capability; the structural surrounds will be designed to preclude jamming.

Injurious Environment

Well-restrained crew members will not contact any major structural elements except possibly flailing extremities such as the feet and hands. Impacts of this type do not normally cause debilitation and postcrash egress should be possible. Internally mounted equipment will be designed to remain in place during a survivable crash impact. This will prevent injuries to occupants caused by flying objects.

WEIGHT PREDICTIONS

Using the design curves developed by the Parametric Sensitivity Analyses and the crashworthiness rating of 94 percent of MIL-STD-1290, as recorded in Appendix H, comparisons were made with the weight estimates obtained from the HESCOMP analyses and summarized in Table 33.

The gross weight for 95°/4000 ft. density altitude designs of metallic and composite structured aircraft obtained from the HESCOMP analysis are 6,085 pounds and 5,607 pounds respectively. Using these values, the 94 percent of

TABLE 33. SUMMARY OF WEIGHT ESTIMATES USING DESIGN CURVES AND HESCOMP

WEIGHT (LB.) / AIRCRAFT	GROSS	MEAN EMPTY	STRUCTURE
"SCOUT" USING DESIGN CURVES:			
• METALLIC	6085	3900	920
• COMPOSITE	5607	3600	700
"SCOUT" USING HESCOMP:			
• METALLIC	6085	3829	928
• COMPOSITE	5607	3439	708

MIL-STD-1290 rating, and the design curves presented in Figures 29 and 31, the airframe weights were predicted.

Table 33 contains results obtained from the design curves and the HESCOMP analyses to allow comparisons to be made between the two methods of prediction. Individual weights of crashworthiness features were predicted using Figures 25, 27, and 28. These values, together with the airframe values, are presented in the summary table in the cost prediction section below.

COST PREDICTIONS

Weight data generated for the "Scout" helicopter were used to develop acquisition, accident and life cycle cost predictions for two aircraft with composite airframes but different percentage of MIL-STD-1290 ratings. This was done to demonstrate the differences that accrue for an aircraft designed to two crashworthiness levels.

Using the units in Figures 32, 33, 34, 35 and 36 the various costs can be estimated for the crashworthiness features. Table 34 contains details of the two designs considered, Scout "A" and Scout "B", and the assumptions made for life-cycle cost analysis. The cost predictions for the two aircraft for the crashworthiness features are presented in Table 35. To assist the reader in following the cost computations, Table 35 contains relevant information sources in parentheses and adjacent to the relevant numbers.

It can be seen from the table that Scout B is more than $17.5 million less expensive to acquire than Scout A for a fleet buy of 1000. However, the accident costs for Scout B over the life cycle are almost $18.5 million higher. Consequently Scout A has a total life cycle cost for crashworthiness which is approximately $1.05 million lower than the corresponding figure for Scout B. This figure may appear to be relatively low but appreciable additional savings may result from the protection offered the expensive avionics-visionics equipment. Such equipment was not defined in sufficient detail, since it is still in the experimental phase of development, to allow reasonable cost data predictions and reasonable assessments of potential damage in a crash.

The costs presented here are not total aircraft life-cycle costs. They are total life-cycle costs related to the crashworthy features. Costs are not included that are

TABLE 34. SCOUT HELICOPTER APPLICATION: INPUT DATA

PARAMETER	SCOUT 'A'	SCOUT 'B'
EMPTY WEIGHT, LB.	3439	3250
PERCENTAGE MIL-STD-RATING (PMSR)	94	80
TWIN ENGINE	NO	NO
COMPOSITE AIRFRAME	NO	NO
ACCIDENT RATE PER 100,000 HOURS	3.0	3.0
NUMBER OF AIRCRAFT	1000	1000
UTILIZATION PER MONTH, HOURS	20	20
LIFE CYCLE, YEARS	20	20

TABLE 35. SCOUT HELICOPTER APPLICATION: OUTPUT DATA FOR CRASHWORTHINESS FEATURES

PARAMETER	SCOUT 'A' (94 PMSR)		SCOUT 'B' (80 PMSR)	
	COST, $	WEIGHT, LB.	COST, $	WEIGHT, LB.
SEATS (2 CREW)	8,300 (FIG. 32)	175 (FIG. 25)	7,650	154
LANDING GEAR	23,000 (FIG. 33)	183 (FIG. 28)	19,000	150
AIRFRAME (*)	128,000 (FIG 35)	690 (FIG. 31)	119,625	560
FUEL SYSTEM	11,000 (FIG 34)	160 (FIG. 27)	7,000	155
TOTAL PER AIRCRAFT	170,800	1280	153,275	1019
1000 AIRCRAFT TOTAL	170,800,000	-	153,275,000	-
ACCIDENT COST PER ACC.	298,370 (FIG. 36 X 0.982)	-	417,350	
144 ACCIDENTS, TOTAL	41,525,280	-	60,098,400	-
TOTAL LIFE CYCLE COST	212,325,280	-	213,373,400	
DELTA WEIGHT	-	189 (A-B)		
DELTA LCC		-	1,048,120 (A-B)	

<u>NOTE</u>: **THE SOURCES OF VALUES CONTAINED IN THE TABLE ARE INCLUDED IN PARENTHESES.**

REFER TO P. 127 FOR CORRECTION FACTORS.

(*) MULTIPLIED BY 0.87 FOR COMPOSITE AIRCRAFT.

common to the aircraft regardless of the particular feature, such as fuel, crew pay and allowances, and aircraft direct maintenance. The addition of common costs would tend to dwarf the cost effects of the crashworthy features.

The accident costs associated with seats are shown to be zero. While it is recognized that there could be accidents at 94 percent of MIL-STD-1290 rating where injuries due to seat problems were involved, the trend data used for these analyses indicate that when the level of crashworthiness exceeds 80 percent the cost impact due to accidents is minimal.

RECOMMENDED CHANGES TO MIL-STD-1290 (AV)

The design specifications used to define crashworthiness contain several anomalies and areas where controversy exists with respect to feasibility and/or acceptability. The primary areas involve the basic structure and the fuel system and these will be addressed here.

In the following recommendations, the relevant sections of MIL-STD-1290 (AV) are referenced in parentheses.

STRUCTURAL DESIGN

Vertical Impact (5.1.2)

The installation of crown mounted crashworthy seat systems should be addressed with respect to the maintenance of adequate stroking distances. The overhead and sidewall structure must be designed to minimize elastic and plastic deformation consistent with seat requirements. This requirement should overrule the 15-percent cabin height reduction for a 42-ft/sec impact when overhead mounted stroking seats are used.

An additional design requirement should be addressed in section 5.1.2.2 with respect to fuselage penetration by ground objects. Floor penetration underneath seated occupants can result in severe acceleration environments, especially so when a collision occurs between a tree stump and a downward moving seat, for example.

Lateral Impact (5.1.3)

During a lateral impact sequence, motion occurs in conflicting directions; the sidewall being crushed inwards while the seat occupant is moving outwards. This is particularly so for forward or aft facing troop passenger seats where occupant lateral motion of about ten inches can occur even when a well adjusted restraint harness is used. In such instances, head motion can be the prime contributor to the displacement.

If lateral attenuation is included in the seat design an additional movement towards the aircraft sidewall will occur.

The 15-percent cabin width reduction requirement for a lateral impact together with the motion of the seat/occupant combination would require about a 2-foot separation

between seats and sidewall to preclude impact injuries.

For metallic aircraft designs and optimum usage of occupant space, the above requirements cannot be met without an untenable reduction of capacity and utilization.

Composite construction, on the other hand, can be designed to be much stiffer for a given weight and minimize the sidewall deflections. However, a stroking distance of 8.4 inches is required to minimize occupant G levels for a 30-ft /sec. impact to the design requirement of 20g assuming constant deceleration. This stroking distance can be achieved by a combination of restrained occupant motion and seat stroking, thus allowing a lesser clearance between occupants and the sidewalls and more efficient space utilization.

Thus for the above crash scenario the cabin width reduction need not be specified; however, a requirement to minimize occupant impact probabilities should be included.

It should be noted in the case of crew seats that clearance is often greater in the cabin. When armored seats with side wings are used, lateral restraint and protection are improved, especially when considering that crew members wear helmets as operational equipment.

POSTCRASH FIRE PREVENTION (5.5)

A great deal of discussion has taken place concerning the desirable impact velocity for drop testing fuel tanks. MIL-T-27422B (Reference 41) defines the drop height of 65 feet which translates to an impact velocity of 65 ft/sec.

The incorporation of crashworthy fuel tanks into existing aircraft designs has demonstrated the validity of the 65-ft/sec test requirement. Survivable crashes have occurred where some fuel spillage resulted. However, the rate of fuel spillage generally was controlled to levels compatible with occupant egress requirements.

Any relaxation in the test requirements will require qualification with respect to installation details of specific aircraft designs. As discussed for occupant protection, a

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[41] TANK, FUEL, CRASH-RESISTANT, AIRCRAFT, MIL-T-27422B, Department of Defense, Washington, D.C. 20301, 24 February 1970

series approach can be taken to predict the energy attenuation offered by the landing gear and structure which interface between the fuel tank and the impact plane. Different aircraft designs can offer differing depths of crushing structure which support the fuel tank as well as to protect against penetration.

The fuel tank is only a part of the total fuel systems of which the pumps, valves and plumbing are sized by flow and redundancy requirements. The tank is the area where acquisition cost and weight reduction is most feasible. However, the analysis has shown that little is gained in these areas when reducing the design requirement from 100 to 80 percent of MIL-STD-1290; especially if ballistic protection is provided while the potential for severe fires is increased. It is recommended that the MIL-STD-1290 requirements for impact conditions be retained. Some flexibility could be introduced into the qualification processes to take into account the "G" environment, location in the airframe, and structural protection as noted above. The definition of such procedures is not within the scope of this program but could be considered as a topic for future research and analysis.

An additional problem that has not been addressed directly in published documentation is the installation of ferry fuel tanks inside of aircraft. Whether the installation uses fuel bladders, metal tanks or other methods of containment, it is usually defined by cargo tie-down requirements. Since these tie-down criteria do not necessarily offer the required level of restraint to sufficiently restrict motion of the installation, and because the cabin may contain a mixture of occupants, fuel cells and cargo, it is imperative that fuel spillage does not occur where occupant survival is possible.

RECOMMENDATIONS

Although a great deal of information is available for metallic construction, the use of composite materials is still being developed for primary structure and total aircraft concepts. Thus it is difficult to predict accident repair costs and life-cycle costs. Additionally, the type of construction employed can vary considerably ranging from multiple material laminates with core materials to simple thermoformed panels. It is recommended that the results of current and future research programs pertaining to composite material usage and repair be used to update the curves contained in this report.

Accident data reporting techniques recently have been improved with respect to crash impacts and the asssessment of structural problem areas and injury causal factors. A future review is recommended to determine if the accident and injury distributions have changed significantly and if so to incorporate changes to the design curves.

As injury potential is reduced with the implementation of crashworthy features such as seats, landing gear, and energy absorbing structure, the impact of operational or people problems may become more apparent. Consistent with design changes it is important that personnel be trained to use all equipment as intended and to follow safety procedures when in or around aircraft. It is recommended that certain designs be investigated to minimize their misuse, such as restraint systems, and also that training procedures be upgraded to reduce casualties due to disciplinary lapses either during operations or after an accident.

Since the use of the design curves as nomograms has built-in inaccuracies, it is recommended that a set of equations be developed from the data for weight and cost estimating.

It is recommended that additional work be done to determine if a "bucket" exists in the life-cycle cost curves for each generic group of helicopters. This would represent the condition when the implementation of additional crashworthiness does not pay off. Such a task would require detailed review of existing and improved designs, full engineering analysis, and detailed cost breakdown and analysis.

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APPENDIX A

OH-6A CRASHWORTHINESS EVALUATION SUMMARY

BASIC FACTOR	HAZARD POTENTIAL	OPTIMUM NUMBER	ACTUAL VALUE
Crew Retention System	17.92%	125	47
Troop Retention System	17.23%	125	36
Postcrash Fire Potential	35.19%	255	196
Basic Airframe Crashworthiness	17.23%	125	72
Evacuation Rating	8.29%	60	60
Injurious Environment	4.14%	30	23
TOTAL	100%	720	434

CRew RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	OH-6A	REMARKS
Vertical Energy Attenuating Capability	30	0	No E/A is provided.
Restraint Webbing Geometry and Strength	25	15	Lapbelt adequate. No lap tiedown strap Shoulder harness of desired strength
Seat Longitudinal Strength	10	2	Seat strength 8G vs 35G desired 8/35 optimum allowed.
Seat Lateral Strength	10	1	Seat strength 3G vs 20G desired 8/25 optimum allowed.
Seat Vertical Strength	10	3	Seat strength 8G vs 25G desired 8/25 of optimum allowed.
Castings in Stressed Areas	10	10	Castings are assumed as not being used.
Shoulder Strap Pull-off Angle	5	3	Shoulder strap pull-off angle less than desired
Lapbelt Angle to Seat Cushion	5	5	Conforms to desired angle
Lapbelt Tiedown Strap	5	0	Not provided

CREW RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	OH-6A	REMARKS
Inertia Reel Types	5	5	Reel used is considered adequate
Depth of Structure Between Floor & Belly	10	3	Depth of structure is minimal; shape is rounded
TOTAL	125	47	

TROOP/PASSENGER RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	OH-6A	REMARKS
Vertical Energy Attenuator Capacity	30	0	No E/A provided
Restraint Webbing and Geometry	20	10	No shoulder harness No lapbelt tiedown strap Lapbelt strength not to desired minimums
Seat Longitudinal Strength	10	3	8G vs 30G desired minimum
Seat Lateral Strength	10	1	8G vs 20G desired minimum
Seat Vertical Strength	10	3	8G vs 25G desired minimum
Castings	10	10	Castings not used
Shoulder Strap Pull-off	10	5	One shoulder harness provided
Lapbelt Angle to Seat Cushion	10	3	Not to desired angle
Lapbelt Tiedown Strap	5	0	No tiedown strap
Depth Structure Between Floor & Belly	10	1	Minimal Rounded Shape Fuel underneath
TOTAL	125	36	

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	OH-6A	REMARKS
Fuel Containment			
Location	12	6	The fuel tank is located directly under the cabin floor. Although remote from heavy masses, ignition sources are likely in hard vertical or longitudinal impacts due to its low location.
Vulnerability	12	10	Assumed crashworthy fuel system has been designed to control hazards.
Construction Techniques	30	30	Cells assumed conforming to 12.7mm self-sealing and crashworthiness requirements
Fuel Boost System	6	4	Boost pumps are used, electrically driven
Oil and Hydraulic Containment	(Includes reservoirs, accumulators, lines and components)		
Location	7	5	Transmission lubrication is integral. Engine oil cooler and lines are located aft of the cabin area.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	OH-6A	REMARKS
Vulnerability	7	5	Oil leakage could penetrate cabin/ cargo area in a severe crash.
Construction Techniques and Tiedown Adequacy	6	4	Fluid lines are assumed to be adequately supported but would more than likely fail in a severe crash. Spillage could come into contact with hot surfaces or ignition surfaces. Part of the fuel line is self-sealing.
Flammable Fluid Lines	30	25	The main transmission fluid lines are integral, whereas the engine fluid lines are not. Fuel lines are assumed self-sealing with frangible connectors.
Firewall	9	9	Engine fire zones are isolated by firewalls to prevent spread of fire.
Fuel Flow Interruptors	9	9	Frangible self-sealing connectors are installed at all fuel cell connections.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	OH-6A	REMARKS
<u>Ignition Control</u>			
Induction & Exhaust Flame Location	30	20	Engine is located above and behind the fuel cells. Fuel mist from ruptured tanks could be ignited by exhaust. Crash-worthy fuel cell mitigates hazards associated with location.
Hot Metals and Shielding	30	24	Engine is located above and behind fuel cells. Therefore, low probability of spilled fluids contacting hot engine parts in upright position. Firewalls minimize the possibility of flammable fluids spilling on hot components.
Engine Location & Tiedown	15	10	Engine location is good with respect to fuel cells. Engine mounts are good for 20, 12, 6G VS 20, 20, 18G per TR 71-22.
Battery Location & Tiedown	12	8	Battery is located in the nose area underfloor, left side. Tiedown has minimium crashload requirements.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	OH-6A	REMARKS
Electrical Wire Routing	12	4	Wire routing is assumed to be running under the floor of the fuel cells. Hazardous during crash conditions.
Fuel Boost System	7	4	Electric fuel pump is submerged on left-hand fuel cell.
Inverter Location & Tiedown Strength	6	5	The inverter(s) is mounted within structure under the pilots seat, which provides the same load factors in a crash sequence.
Generator Location & Tiedown Strength	6	5	The generator is mounted on the engine power and accessory gearbox. The tiedown strength would be the same as for the engine; 20, 12, & 6Gs.
Lights Location & Tiedown	5	4	The landing light is located on the nose, flush with lower surface of the canopy. Anti-collision underneath the pilot compartment. Possible ignition sources.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	OH-6A	REMARKS
Antenna Location & Tiedown Strength	4	4	Some antennas are mounted on top of canopy and above tail boom. The ADF Loop Antenna, ADF Sense Antenna and IFF Antenna are located under the cockpit.
TOTAL	255	196	

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	OH-6A	REMARKS
Crushing of Occupied Troop/ Passenger Areas	10	8	Distance from nose to troop seats is only a few feet, which is considered marginal to prevent crushing during a survivable impact. Vertical structure adequate to support mass items.
Absence of Plowing	20	10	Underfloor structure is not designed to prevent plowing.
Resistance to Longitudinal Impact Loads	10	6	The airframe structure provides some load carrying ability via the cabin door frames and geometry of design.
Resistance to Vertical Impact Loads	30	15	Underfloor structure is not very effective but restraint of large mass items adequate.
Resistance to Lateral & Roll-over Impact Loads	20	10	Roll capability is good; lateral impact resistance is low.
Landing Gear Vertical Force Attenuation	20	10	Landing gear is good for 13.5-ft/sec vertical impact velocity without ground contact. (skid gear + dampers).

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	OH-6A	REMARKS
Landing Gear Location	5	3	Landing gear attachment under the pilot seat could cause problems.
Effect of Blade Separation on Cabin Occupants	5	5	Hazardous effect on occupants considered remote.
Effect of Fuselage Fracture/Separation	5	5	Tail boom fracture/separation will not affect occupiable area.
TOTAL	125	72	

EVACUATION RATING

SUBFACTOR	OPTIMUM NUMBER	OH-6A	REMARKS
Ease and Reliability of Exit Operation	15	15	Each door is jettisonable by pulling the cabin loop handle.
Ratio of Usable Exits to Occupants	15	15	A ratio of one exit per 10 occupants is considered to be minimum acceptable. One primary exit per cabin occupant is provided.
Availability of Exits in Rolled Aircraft	10	10	A minimum of one exit per two occupants is available vs one per 10 desired.
Identification of Exits	10	10	Identification of emergency exits is of no importance.
Emergency Lighting	10	10	Emergency lighting not required.
TOTAL	60	60	

INJURIOUS ENVIRONMENT

SUBFACTOR	OPTIMUM NUMBER	OH-6A	REMARKS
Proximity of Cockpit Panels & Controls	10	8	Low probability of structural contact for cockpit occupants with lap belt and shoulder harness.
Anti-Torque Pedal Area	5	4	Low probability of trapping feet.
Absence of injurious Objects in Cabin	5	4	Minimum protrusions. Single shoulder harness minimizes probability of injury.
Retention of Interior Equipment	10	7	Equipment in immediate vicinity of occupants is restrained to 17G vs recommended 25G.
TOTAL	30	23	

APPENDIX B

OH-58 CRASHWORTHINESS EVALUATION SUMMARY

BASIC FACTOR	HAZARD POTENTIAL	OPTIMUM NUMBER	ACTUAL VALUE
Crew Retention System	17.92%	125	58
Troop Retention System	17.23%	125	35
Post Crash Fire Potential	35.19%	255	203
Basic Airframe Crashworthiness	17.23%	125	48
Evacuation	8.29%	60	50
Injurious Environment	4.14%	30	19
TOTAL	100%	720	413

CREW RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	OH-58	REMARKS
Vertical Energy Attenuating Capability	30	0	No E/A is provided
Restraint Webbing Geometry & Strength	25	15	Lapbelt adequate Shoulder harness marginal of desired strength - No lap tiedown strap
Seat Longitudinal Strength	10	6	Seat strength 20G vs 35G desired ∴ 20/35 optimum allowed
Seat Lateral Strength	10	5	Seat strength 10G vs 20G desired ∴ 10/20 of optimum allowed
Seat Vertical Strength	10	8	Seat strength 20G vs 25G desired ∴ 20/25 of optimum allowed
Castings in Stressed Areas	10	10	Castings are not used
Shoulder Strap Pull-Off Angle	5	3	Shoulder strap pull-off angle less than desired
Lapbelt Angle to Seat Cushion	5	5	Angle conforms to desired angle of 45°
Lapbelt Tiedown Strap	5	0	Not provided
Inertia Reel Types	5	5	Reel used is considered adequate
Depth of Structure Between Floor & Belly	10	1	Depth of Structure is minimal
TOTAL	125	58	

TROOP RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	OH-58	REMARKS
Vertical Energy Attenuator Capacity	30	0	No E/A provided
Restraint Webbing and Geometry	20	10	Lapbelt marginal Shoulder harness marginal. No lap tiedown strap
Seat Longitudinal Strength	10	2	Troop seats are part of the fuel cell structure. Seat strength 8G vs 35G desired ∴ 8/35 optimum allowed.
Seat Lateral Strength	10	2	Seat strength 4G vs 20G desired ∴ 4/20 of optimum allowed.
Seat Vertical Strength	10	2	Seat strength 8G vs 25G desired ∴ 8/25 of optimum allowed. Fuel tank strength decreases due to occupant weight.
Castings in Stressed Areas	10	10	No castings
Shoulder Strapp Pull-off	10	6	Pull-off angle less than desired
Lapbelt Angle to Seat Cushion	10	3	Does not conform to desired angle. Seat geometry changes due to change in fuel quantity.
Lapbelt Tiedown Strap	5	0	Not provided
Depth Structure Between Floor & Belly	10	0	Depth of structure is minimal
TOTAL	125	35	

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	OH-58	REMARKS
Fuel Containment			
Location	12	4	Fuel cell is located in the lower right side of cabin area, a few inches above the skin line and above the aft landing gear attachment. Ignition sources likely; battery location aft of cell. Crashworthy fuel system.
Vulnerability	12	8	Crashworthy system reduces structural displacement hazards. Landing gear failure poses hazard. Ignition sources likely
Construction Techniques	30 .	30	Crashworthy self-sealing fuel system is assumed.
Fuel Boost System	6	4	Boost pumps are used for normal flight
Oil and Hydraulic Containment	(Includes reservoirs, accumulators, lines and components)		
Location	7	5	Integral lubrication-components located away from major impact areas but are centralized above the cabin area.
Vulnerability	7	5	Components are located in areas of low criticality.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	OH-58	REMARKS
Construction Techniques and Tiedown Adequacy	6	4	Hydraulic components are adequately supported but would more than likely fail in a severe crash. Spillage could come into contact with hot surfaces or ignition sources.
Flammable Fluid Lines	30	25	Main transmission lubrication is integral with internal wet sump. Engine lubrication has external oil tank, cooler, lines, values, etc. Only protection is shielding from other components. Tail rotor transmission has self-contained lubrication.
Firewall	9	9	Engine fire zones are isolated by firewalls to prevent spread of fire.
Fuel Flow Interruptors	9	9	Frangible self-sealing connectors are assumed to be installed at all fuel cell connections.
<u>Ignition Control</u>			
Induction and Exhaust Flame Location	30	26	Engine is located above the fuel cell. Fuel mist from

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	OH-58	REMARKS
			ruptured tank could be ignited by induction in a rollover situation. Crashworthy fuel cell mitigates hazards associated with location.
Hot Metals and Shielding	30	24	Engine is located above fuel cell. Therefore low probability of spilled fluids contacting hot engine parts in upright position. Engine firewalls minimize the possibility of flammable fluids spilling on hot components.
Engine Location and Tiedown	15	12	Engine location is good with respect to fuel cell. Engine mounts are good for 16, 16, 8G vs 20, 20, 18G per TR 71-22.
Battery Location and Tiedown	12	6	Battery is located in compartment aft of fuel cell. Tiedown has minimum crashload requirements.
Electrical Wire Routing	12	10	Wire installations conform to MIL-W-5088. Wiring is assumed to be routed suffici-

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	OH-58	REMARKS
			ently high in the fuselage such that deformation of structure during a survivable crash should have little effect on line continuity.
Fuel Boost System	7	4	One boost pump is used
Transformer Rectifier Location & Tiedown Strength	6	4	Assume to conform to minimum crash-load requirements.
Generator Location & Tiedown Strength	6	5	An electric starter-generator is used. Tiedown strength is assumed to be the same as the general requirements of 16, 16 & 8 Gs.
Lights Location & Tiedown Strength	5	4	The landing and search lights located on the underside of the nose could become ignition sources during crash sequence.
Antenna Location & Tiedown Strength	4	4	UHF antenna is located on the underside of fuselage. Could be ignition source.
TOTAL	255	203	

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	OH-58	REMARKS
Crushing of Occupied Troop/ Passenger Areas	10	6	Distance from nose to passenger area is considered less than marginal to prevent crushing during a survivable crash sequence.
Absence of Plowing	20	10	Underfloor structure is not designed to prevent plowing.
Resistance to Longitudinal Impact Loads	10	5	The airframe structure does not provide good shear strength due to large side doors.
Resistance to Vertical Impact Loads	30	8	Structure assumed to be designed to 8G vs 20G required.
Resistance to Lateral & Roll-Over Impact Loads	20	5	Structure assumed to be designed to 8G vs 20G requirement for lateral loads.
Landing Gear Vertical Force Attenuation	20	5	Landing gear allows for no attenuation.
Landing Gear Location	5	3	Landing gear location could puncture fuel tank in a severe crash.
Effect of Blade Separation on Cabin Occupants	5	1	Hazardous effect on occupants.
Effects of Fuselage Fracture/Separation	5	5	Tail boom fracture/ separation will not affect occupiable area.
TOTAL	125	48	

EVACUATION RATING

SUBFACTOR	OPTIMUM NUMBER	OH-58	REMARKS
Ease & Reliability of Exit Operation	15	15	Pilot & copilot doors are jettisonable by means of a single release handle. Size and operation of emergency exits conform to HIAD. Emergency door protection against accidental release is provided.
Ratio of Usable Exits to Occupant	15	15	A ratio of one exit per 10 occupants is considered to be minimum acceptable. One primary exit per two or three cabin occupants is provided under worst conditions.
Availability of Exits in Rolled Aircraft	10	10	A minimum of one exit per two or three occupants is available vs one per ten desired.
Identification of Exits	10	10	Exits are assumed to have proper identification
Emergency Lighting	10	0	No provisions for emergency lighting.
TOTAL	60	50	

INJURIOUS ENVIRONMENT

SUBFACTOR	OPTIMUM NUMBER	OH-58	REMARKS
Proximity of Cockpit Panels and Controls	10	8	Low probability of structural contact for cockpit occupants with lapbelt and shoulder harness.
Anti-Torque Pedal Area	5	2	Crushing of lower nose structure could trap feet
Absence of Injurious Objects in Cabin	5	4	Cabin was designed with minimum protrusions. Shoulder harness for cabin occupants minimizes probability of injury.
Retention of Interior Equipment	10	5	Equipment in immediate vicinity of occupants is restrained on the average to 13G vs recommended 25G.
TOTAL	30	19	

APPENDIX C

UH-1 H CRASHWORTHINESS EVALUATION SUMMARY

BASIC FACTOR	HAZARD POTENTIAL	OPTIMUM NUMBER	ACTUAL VALUE
Crew Retention System	17.92%	125	50
Troop Retention System	17.23%	125	40
Postcrash Fire Potential	35.19%	255	200
Basic Airframe Crashworthiness	17.23%	125	47
Evacuation	8.29%	60	45
Injurious Environment	4.14%	30	17
TOTAL	100%	720	399

CREW RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	UH-1H	REMARKS
Vertical Energy Attenuating Capability	30	0	No E/A is provided.
Restraint Webbing Geometry and Strength	25	15	Lapbelt adequate Shoulder harness inadequate of desired strength. No lap tiedown strap
Seat Longitudinal Strength	10	2	Seat strength 8G vs 35G desired ∴ 8/35 optimum allowed.
Seat Lateral Strength	10	4	Seat strength 8G vs 20G desired ∴ 8/20 optimum allowed.
Seat Vertical Strength	10	3	Seat strength 8G vs 25G desired ∴ 8/25 of optimum allowed.
Castings in Stressed Areas	10	10	Castings are not used.
Shoulder Strap Pull-off Angle	5	3	Shoulder strap pull-off angle less than desired
Lapbelt Angle to Seat Cushion	5	5	Conforms to desired angle (45°)
Lapbelt Tiedown Strap	5	0	Not provided
Inertia Reel Types	5	5	Reel used is considered adequate

CREW RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	UH-1H	REMARKS
Depth of Structure Between Floor & Belly	10	3	Approx 12" is provided. Shape is flat
TOTAL	125	50	

TROOP RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	UH-1H	REMARKS
Vertical Energy Attenuator Capacity	30	0	No E/A provided
Restraint Webbing and Geometry	20	12	No shoulder harness No lapbelt tiedown strap Lapbelt strength not to desired minimums
Seat Longitudinal Strength	10	3	8G vs 30G desired minimum
Seat Lateral Strength	10	4	8G vs 20G desired minimum
Seat Vertical Strength	10	3	8G vs 25G desired minimum
Castings	10	10	Castings not used
Shoulder Strap Pull-off	10	0	Shoulder harness not provided
Lapbelt Angle to Seat Cushion	10	5	Lapbelt angle not to desired degree
Lapbelt Tiedown Strap	5	0	No tiedown strap
Depth Structure Between Floor & Belly	10	3	14" structure provided Flat shape Fuel underneath
TOTAL	125	40	

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CRASHWORTHINESS DESIGN PARAMETER SENSITIVITY ANALYSIS.(U)
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POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	UH-1H	REMARKS
Spillage Control:			
Fuel Containment			
Location	12	10	Two of the five fuel tanks are directly under the cabin floor. Although remote from heavy masses, ignition sources are likely in hard vertical or longitudinal impacts. Crashworthy fuel system mitigates potential hazard.
Vulnerability	12	10	Crashworthy system has been designed to control hazards associated with structural displacement. Landing gear failures very likely, due to gear type, do pose a hazard due to location.
Construction Techniques	30	30	Cells conform to MIL-T-27422 requirements
Fuel Boost System	6	4	Boost pumps are used located within cells, electrically driven

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	UH-1H	REMARKS
<u>Oil and Hydraulic Containment</u>	(Includes reservoirs, accumulators, lines and components)		
Location	7	5	Integral lubrication components located away from major impact areas but are centralized above the cabin area.
Vulnerability	7	5	Component locations are generally in areas not subjected to major distortion in a survivable crash
Construction Techniques and Adequacy	6	4	Hydraulic components are adequately supported but would more than likely fail in a severe crash. Spillage could come into contact with hot surfaces or ignition sources.
Flammable Fluid Lines	30	25	The transfer of flammable fluids within the aircraft are integral for the main, tail and intermediate transmissions, thereby minimizing leakage. Fuel lines are self-sealing with frangible connectors.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	UH-1H	REMARKS
Firewall	9	9	Engine fire zones are isolated by firewalls to prevent spread of fire.
Fuel Flow Interruptors	9	9	Frangible self-sealing connectors are installed at all fuel cell connections.
<u>Ignition Control</u>			
Induction & Exhaust Flame Location	30	20	Engines are located above the fuel cells. Fuel mist from ruptured tanks could be ignited by exhaust. Crashworthy fuel cell mitigates hazards associated with location.
Hot Metals and Shielding	30	24	Engines are located above fuel cells. Therefore, low probability of spilled fluids contacting hot engine parts in upright position. Firewalls minimize the possibility of flammable fluids spilling on hot components.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	UH-1H	REMARKS
Engine Location & Tiedown	15	5	Engine locations are good with respect to fuel cells. Engine mounts are good for 8, 8 & 1.5G vs 20, 20 & 18 per TR 71-22.
Battery Location & Tiedown	12	8	Battery is located in the nose area. Tiedown has minimium crashload requirements.
Electrical Wire Routing	12	10	Wire installation conforms to MIL-W-5088. Wiring is assumed to be routed sufficiently high in the fuselage such that deformations of structure during a survivable crash should have little effect on line continuity.
Fuel Boost System	7	4	Electric motor-driven submerged fuel pumps are used.
Transformer Rectifier Location & Tiedown Strength	6	5	Location is assumed to be in the nose of the aircraft and tiedown conforms to minimum crashload requirements.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	UH-1H	REMARKS
Generator Location & Tiedown Strength	6	5	The generator is mounted on the transmission assembly. Tiedown strength is assumed to be the same as the general requirement of 8, 8, & 8Gs.
Lights Location & Tiedown Strength	5	4	The landing light and search light located on the underside of the fuselage could become ignition sources during crash sequence.
Antenna Location & Tiedown Strength	4	4	Some antennas are assumed to be located on underside of fuselage; they could be ignition sources.
TOTAL	255	200	

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	UH-1H	REMARKS
Crushing of occupied Troop/ Passenger Areas	10	4	Distance from nose to first seat row is 7 feet, which is considered marginal to prevent crushing during a survivable crash sequence.
Absence of Plowing	20	10	Underfloor structure is not designed to prevent plowing.
Resistance to Longitudinal Impact Loads	10	4	The airframe structure provides little shear strength due to large side doors. 8G vs 20G required.
Resistance to Vertical Impact Loads	30	8	Structure designed to 8G vs 20G required
Resistance to Lateral & Roll-over Impact Loads	20	5	Structure designed to 8G vs 20G requirement for lateral loads.
Landing Gear Vertical Force Attenuation	20	5	Landing gears allow for no attenuation (skids only)
Landing Gear Location	5	5	Landing gear location should pose no problem.
Effect of Blade Separation on Cabin Occupants	5	1	Hazardous effect on occupants.

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	UH-1H	REMARKS
Effect of Fuselage Fracture/Separation	5	5	Tail boom fracture/ separation will not affect occupiable area.
TOTAL	125	47	

EVACUATION RATING

SUBFACTOR	OPTIMUM NUMBER	UH-1H	REMARKS
Ease and Reliability of Exit Operation	15	10	Pilot and copilot doors are jettisonable by means of a single release handle. Size and operation of emergency exits conform to HIAD. Each side troop door is provided with two ground emergency escape panels.
Ratio of Usable Exits to Occupants	15	15	A ratio of one exit per 10 occupants is considered to be minimum acceptable. One primary exit per 5 or 6 cabin occupants is provided under worst conditions.
Availability of Exits in Rolled Aircraft	10	10	A minimum of one exit per 6.5 occupants is available vs one per 10 desired.
Identification of Exits	10	10	Identification of emergency exits is in accordance with MIL-A-25165.
Emergency Lighting	10	0	No provisions for emergency lighting.
TOTAL	60	45	

INJURIOUS ENVIRONMENT

SUBFACTOR	OPTIMUM NUMBER	UH-1H	REMARKS
Proximity of Cockpit Panels & Controls	10	8	Low probability of structural contact for cockpit occupants with lap belt and shoulder harness.
Anti-Torque Pedal Area	5	2	Crushing of lower nose structure could trap feet.
Absence of injurious objects in cabin	5	4	Cabin was designed with minimum protrusions. Shoulder harness for cabin occupants minimizes probability of injury.
Retention of Interior Equipment	10	3	Equipment in immediate vicinity of occupants is restrained to 8G vs recommended 25G.
TOTAL	30	17	

APPENDIX D

AH-1G CRASHWORTHINESS EVALUATION SUMMARY

BASIC FACTOR	HAZARD POTENTIAL	OPTIMUM NUMBER	ACTUAL VALUE
Pilot Retention System	17.23%	125	59
Gunner Retention System	17.92%	125	53
Postcrash Fire Potential	35.19%	255	211
Basic Airframe Crashworthiness	17.23%	125	50
Evacuation	8.29%	60	55
Injurious Environment	4.14%	30	27
TOTAL	100%	720	455

GUNNER RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	AH-1G	REMARKS
Vertical Energy Attenuating Capability	30	0	No E/A is provided.
Restraint Webbing Geometry and Strength	25	15	Lapbelt adequate. Shoulder harness of inadequate strength. No lap tiedown strap
Seat Longitudinal Strength	10	4	Seat strength 15G vs 35G desired ∴ 15/35 optimum allowed.
Seat Lateral Strength	10	2	Seat strength 5G vs 20G desired ∴ 5/20 optimum allowed.
Seat Vertical Strength	10	6	Seat strength 15G vs 25G desired ∴ 15/25 of optimum allowed.
Castings in Stressed Areas	10	10	Assumed no castings are used.
Shoulder Strap Pull-off Angle	5	3	Assumed pull-off angle less than desired
Lapbelt Angle to Seat Cushion	5	5	Conforms to desired angle (45°)
Lapbelt Tiedown Strap	5	0	Assumed not provided
Inertia Reel Types	5	5	Reel is assumed to be adequate

GUNNER RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	AH-1G	REMARKS
Depth of Structure Between Floor & Belly	10	3	Although depth of structure between floor & belly is considerable most of it (Ammo bay, turret & gun) is non-crushable.
TOTAL	125	53	

PILOT RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	AH-1G	REMARKS
Vertical Energy Attenuating Capability	30	0	No E/A is provided.
Restraint Webbing Geometry and Strength	20	15	Lapbelt adequate Shoulder harness of inadequate strength. No lap tiedown strap
Seat Longitudinal Strength	10	4	Seat strength 15G vs 35G desired ∴ 15/35 optimum allowed.
Seat Lateral Strength	10	2	Seat strength 5G vs 20G desired ∴ 5/20 optimum allowed.
Seat Vertical Strength	10	6	Seat strength 15G vs 25G desired ∴ 15/25 of optimum allowed.
Castings in Stressed Areas	10	10	Assumed no castings are used.
Shoulder Strap Pull-off Angle	10	7	Assumed pull-off angle less than desired
Lapbelt Angle to Seat Cushion	10	10	Conforms to desired angle (45°)
Lapbelt Tiedown Strap	5	0	Assumed not provided

PILOT RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	AH-1G	REMARKS
Depth of Structure Between Floor & Belly	10	5	Although depth of structure between floor & belly is considerable most of it (Ammo bay, turret & gun) is relatively non-crushable.
TOTAL	125	59	

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	AH-1G	REMARKS
<u>Spillage Control</u>:			
<u>Fuel Containment</u>			
Location	12	10	Fuel tanks are behind & below pilot compartment. Landing gear could rupture tanks in a crash situation. Crashworthy fuel system somewhat mitigates hazard.
Vulnerability	12	10	Crashworthy system has been designed to control hazards associated with structural displacement. Landing gear failures due to gear type and location are very likely, and do pose a problem.
Construction Techniques	30	30	Cells conform to MIL-T-27422 requirements
Fuel Boost System	6	4	Boost pumps are used.
<u>Oil and Hydraulic Containment</u>			
Location	7	7	Integral lubrication components located away from major impact areas.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	AH-1G	REMARKS
Vulnerability	7	5	Component locations are generally in areas not subjected to major distortion in a survivable crash
Construction Techniques and Tiedown Adequacy	6	4	Hydraulic components are adequately supported but would more than likely fail in a severe crash. Spillage could come into contact with hot surfaces or ignition sources.
Flammable Fluid Lines	30	25	The transfer of flammable fluids within the aircraft are integral for the main, tail and intermediate transmissions, thereby minimizing leakage. Fuel lines are self-sealing with frangible connectors.
Firewall	9	9	Engine fire zones are isolated by firewalls to prevent spread of fire.
Fuel Flow Interruptors	9	9	Frangible self-sealing connectors are assumed installed at all fuel cell connections.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	AH-1G	REMARKS
<u>Ignition Control</u>			
Induction & Exhaust Flame Location	30	25	Engine is located above and aft the fuel cells so that fuel mist from ruptured tanks provides a remote possibility for ignition. Crashworthy fuel cell mitigates hazards associated with location.
Hot Metals and Shielding	30	24	Engine is located above and aft of fuel cells. Therefore, low probability of spilled fluids contacting hot engine parts in upright position. Firewalls minimize the possibility of flammable fluids spilling on hot components.
Engine Location & Tiedown	15	10	Engine location is good with respect to fuel cells. Engine mounts are good for 15, 15 8G vs 20, 20 & 18G per TR 71-22.
Battery Location & Tiedown	12	6	Battery is located behind the aft fuel cell. Possible ignition source if cell ruptures. Tiedown has minimium crashload requirements.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	AH-1G	REMARKS
Electrical Wire Routing	12	10	Electrical wiring is assumed to be routed sufficiently high in the fuselage such that deformations of structure during a survivable crash should have little effect on line continuity.
Fuel Boost System	7	4	Fuel boost pumps are used.
Transformer Rectifier Location & Tiedown Strength	6	6	Location is assumed to be in electronics compartment in the tail boom.
Generator Location & Tiedown Strength	6	5	The generator is assumed to be mounted on the transmission assembly. Tiedown strength is 8, 8, & 4Gs.
Lights Location & Tiedown Strength	5	4	Search light is located on the nose of the aircraft. It could become ignition source during crash conditions.
Antenna Location & Tiedown Strength	4	4	All antennas are assumed to be located on upper side of fuselage.
TOTAL	255	211	

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	AH-1G	REMARKS
Distance From Nose to Troop/Passenger Area	10	10	Pilot location regarded as cabin for this analysis since AH-1G does not have a troop area. A reasonable amount of crushable structure is provided between the pilot and probable point of impact.
Absence of Plowing	20	10	Underfloor structure is not designed to prevent plowing.
Resistance to Longitudinal Impact Loads	10	5	The airframe structure should provide good shear strength but gunner situated in the nose.
Resistance to Vertical Impact Loads	30	5	Structural strength (for XMSN and engine) 12G vs 20G required but gun turret and ammunition boxes will preclude attenuation.
Resistance to Lateral & Roll-over Impact Loads	20	5	Structure designed to 5G vs 20G requirement for lateral loads.
Landing Gear Vertical Force Attenuation	20	5	Landing gears do not have attenuators (skids only)

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	AH-1G	REMARKS
Landing Gear Location	5	2	Landing gear could puncture fuel tanks in a severe vertical crash.
Effect of Blade Separation on Cabin Occupants	5	3	Hazardous effect on gunner more probable.
Effect of Fuselage Fracture/Separation	5	5	Fuselage fracture/ separation will not affect occupiable area.
TOTAL	125	50	

EVACUATION RATING

SUBFACTOR	OPTIMUM NUMBER	AH-1G	REMARKS
Ease and Reliability of Exit Operation	15	15	Pilot and gunner canopy doors are easily opened.
Ratio of Usable Exits to Occupants	15	15	A ratio of one exit per 10 occupants is considered to be minimum acceptable. Two exits per occupant are assumed to be provided (one per each side of the aircraft).
Availability of Exits in Rolled Aircraft	10	5	A minimum of one exit per occupant is required. One occupant trapped unless he can cut through canopy on other side.
Identification of Exits	10	10	Identification of emergency exits is of no importance.
Emergency Lighting	10	10	Not required on this aircraft.
TOTAL	60	55	

INJURIOUS ENVIRONMENT

SUBFACTOR	OPTIMUM NUMBER	AH-1G	REMARKS
Proximity of Cockpit Panels & Controls	10	10	Low probability of structural contact for cockpit occupants with lap belt and shoulder harness.
Anti-Torque Pedal Area	5	2	Crushing of nose structure could trap feet of gunner.
Absence of injurious objects in cabin	5	5	Cockpit panels for gunner & pilot are only possible protrusions. Shoulder harness minimizes probability of injury.
Retention of Interior Equipment	10	10	No equipment is in immediate vicinity of pilot & gunner
TOTAL	30	27	

APPENDIX E

YUH-61A CRASHWORTHINESS EVALUATION SUMMARY

BASIC FACTOR	HAZARD POTENTIAL	OPTIMUM NUMBER	ACTUAL VALUE
Crew Retention System	17.92%	125	118
Troop Retention System	17.23%	125	123
Postcrash Fire Potential	35.19%	255	224
Basic Airframe Crashworthiness	17.23%	125	123
Evacuation	8.29%	60	45
Injurious Environment	4.14%	30	25
TOTAL	100%	720	658

CREW RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	YUH-61A	REMARKS
Vertical Energy Attenuating Capability	30	25	Pilot, copilot and gunner seats will conform with MIL-S-58095 except 12" vertical stroke (11" provided)
Restraint Webbing Geometry and Strength	25	25	Will conform to MIL-S-58095 requirements.
Seat Longitudinal Strength	10	10	Will conform to MIL-S-58095
Seat Lateral Strength	10	10	Will conform to MIL-S-58095
Seat Vertical Strength	10	10	Will conform to MIL-S-58095
Absence of Castings in stressed areas	10	10	Will conform - no castings in critically stressed areas
Shoulder Strap Pull-off Angle	5	5	Will conform to MIL-S-58095 requirements
Lapbelt Angle to Seat Cushion	5	5	Will conform (45° to 55° requirement)
Lapbelt Tiedown Strap	5	5	Will conform to MIL-S-58095 requirement
Inertia Reel Types	5	5	Will conform to MIL-S-58095 requirements
Depth of Structure Between Floor & Belly	10	8	The present design approach does not rely excessively on structural deformation for the 95th percentile survivable accident
TOTAL	125	118	

TROOP RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	YUH-61A	REMARKS
Vertical Energy Attenuator Capacity	30	30	Troop seats will conform to MIL-S-58095 (12" vertical stroke)
Restraint Webbing and Geometry	20	20	Will conform to MIL-S-58095 requirements
Seat Longitudinal Strength	10	10	Will conform to MIL-S-58095
Seat Lateral Strength	10	10	Will conform to MIL-S-58095
Seat Vertical Strength	10	10	Will conform to MIL-S-58095
Absence of Casting in Stressed Areas	10	10	Will conform - no castings in critically stressed areas
Shoulder Strap Pull-off Angle	10	10	Double shoulder straps conform to 0° to 25° angle
Lapbelt Angle to Seat Cushion	10	10	Will conform (45° to 55° requirement)
Lapbelt or Side Tiedown Strap	5	5	Will conform to MIL-S-58095 requirement
Depth Structure Between Floor & Belly	10	8	The present design approach does not rely excessively on structural deformation for the 95th percentile survivable accident.
TOTAL	125	123	

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	YUH-61A	REMARKS
Fuel Containment	60	50	Fuel cells are relatively remote from engine and isolated from occupied areas. Fuel cells and attachments shall conform to MIL-T-27422 and TR 71-22. Construction of fuel cells will be from crash resistant material and self-sealing against a 14.5mm threat. Cells are compact and regularly shaped. Frangible self-sealing couplings will be used at all fuel cell connections and at each engine bay firewall to reduce fuel spillage.
Oil and Hydraulic Containment	20	16	All transmissions, except for the two engine transmissions, have completely integral oil supplies. Tiedowns are designed for crash survivable loads. Spillage could come into contact with hot surfaces or ignition sources.
Flammable Fluid	30	25	The transfer of flammable fluids within the aircraft has been minimized by utilizing, where possible, integral lubrication systems within transmissions and engines.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	YUH-61A	REMARKS
			Fuel lines from the fuel cells to the engines are self-sealing with frangible self-sealing connectors for all pipe connections to the fuel cells and through the engine bay firewalls. Hydraulic fluid lines are located in the main rotor equipment bay area except for brakes, the kneeling system, and the tail rotor control actuators.
Firewall	9	9	Engine fire zones are isolated by firewalls to prevent spread of fire.
Fuel Flow Interruptors	9	9	Frangible self-sealing connectors are installed at all fuel cell connections and where fuel lines traverse engine bay firewalls.
<u>Ignition Control</u>			
Induction & Exhaust Flame Location	30	26	Engines are high above the ground and located above the crashworthy fuel cells. There is a possibility, in the event of fuel spillage, that fuel mist could be ingested into the engines. Then, should induction flames occur, they would probably

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	YUH-61A	REMARKS
			propagate forward into the spilled fluid. With respect to the engine exhausts, the fluid could be ignited if the aircraft were to skid forward into the path of the spilled fluids.
Location of Hot Metals and Shielding	30	28	Engines are located above the fuel cells. Hence, low probability of spilled fluids contacting hot engine parts while the aircraft remains upright. Firewalls isolate the engines from the rotor transmission area (minimizes possibility of flammable fluids spilling on hot components).
Engine Location and Tiedown Strength	15	13	Engine locations are good with respect to fuel cells. Engine mounts are redundant and conform to crashload requirements.
Battery Location and Tiedown Strength	12	10	Battery is located in the nose area, STN 15-21. Tiedown will conform to crashload requirements.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	YUH-61A	REMARKS
Electrical Wire Routing	12	10	Sufficient length of wiring will be provided in potential ignition areas to allow for airframe deformation during crash without causing wire fractures.
Fuel Boost System	7	7	No fuel boost system - engine fuel pumps suction system used.
Transformer Rectifier Location & Tiedown Strength	6	6	Location in the nose of the aircraft is remote from fuel tanks. Tiedown will conform to crashload requirements.
Generator Location & Tiedown Strength	6	6	One generator is coupled to the forward A.G.B. and one to the aft A.G.B. Tiedown will conform to crashload requirements.
Lights Location & Tiedown Strength	5	5	Tiedown will conform to crashload requirements
Antenna Location & Tiedown Strength	4	4	Tiedown will conform to crashload requirements.
TOTAL	255	224	

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	YUH-61A	REMARKS
Distance From Nose to Troop/ Passenger Areas	10	10	The airframe structure is specifically designed to the longitudinal impact condition.
Absence of Plowing	20	20	Nose has a smooth contour. Tough ductile belly skin, longitudinal under floor beams.
Resistance to Longitudinal Impact Loads	10	10	The airframe structure specifically designed to the longitudinal impact condition.
Resistance to Vertical Impact Loads	30	30	Structure designed in excess of vertical load factor requirements.
Resistance to Lateral & Roll-over Impact Loads	20	20	Mission requirements necessitate large cutouts, however, structure has been strengthened.
Landing Gear Vertical Force Attenuation	20	20	Landing gears is designed to 30 ft/sec.
Landing Gear Location	5	3	Main gear is in optimum location. Nose gear is in close proximity to crew.
Effect of Blade Separation on Cabin Occupants	5	5	Hazardous effect on occupants considered remote provided occupants remain in cabin.
Effect of Fuselage Fracture/Separation	5	5	Maximum strength is in cabin area.
TOTAL	125	123	

EVACUATION RATING

SUBFACTOR	OPTIMUM NUMBER	YUH-61A	REMARKS
Ease and Reliability of Exit Operation	15	15	Will conform with PIDS requirement 3.7.3.3.4.
Ratio of Usable Exits to Occupants	15	15	Ratio of occupants to usable exits in troop compartment, is 3:1 (Optimum is 3:1).
Availability of Exits in Rolled Aircraft	10	5	Ratio of occupants to usable exits in troop compartment, in event of roll over, is 6:1 (Optimum is 3:1).
Identification of Exits	10	10	Will conform.
Emergency Lighting	10	0	No provisions for emergency lighting. (NOTE: was offered as an option in original proposal).
TOTAL	60	45	

INJURIOUS ENVIRONMENT

SUBFACTOR	OPTIMUM NUMBER	YUH-61A	REMARKS
Proximity of Cockpit Panels & Controls	10	8	Low probability of structural contact for cockpit occupants with lapbelt restraint and lateral movement permitted by shoulder harness, except for possible limb flailing under some crash conditions.
Retention of Interior Equipment	10	10	Will conform to requirements of load factors defined in PIDS 3.2.2.4.4.1.
Rudder Pedal Area	5	3	Crushed nose could trap pilot/copilot's feet.
Absence of injurious objects in cabin	5	4	Cabin has been designed with a minimum of protrusions. Double shoulder harness for troops' and gunners' locations minimizes probability of injury.
TOTAL	30	25	

APPENDIX F

CH-47C AND CH-47D CRASHWORTHINESS EVALUATION SUMMARY

BASIC FACTOR	HAZARD POTENTIAL	OPTIMUM NUMBER	CH-47C	CH-47D
Crew Retention System	17.92%	125	52	52
Troop Retention System	17.75%	125	44	44
Postcrash Fire Potential	35.12%	255	172	210
Basic Airframe Crashworthiness	17.23%	125	84	99
Evacution	8.29%	60	51	51
Injurious Environment	4.14%	30	24	24
Total	100%	720	427	480

CREW RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
Vertical Energy Attenuating Capability	30	0	0	No E/A is provided
Restraint Webbing Geo. and Strength	25	15	15	Lapbelt adequate Shoulder harness 50% desired strength No lapbelt tie-down strap Shoulder harness webbing thickness .04 vs .09 desired
Seat Longitudinal Strength	10	2	2	Seat strength 8G vs 35G desired ∴ 8/35 of optimum allowed
Seat Lateral Strength	10	4	4	Seat strength 8G vs 20G desired ∴ 8/20 optimum allowed
Seat Vertical Strength	10	3	3	Seat strength 8G vs 25G desired ∴ 8/25 optimum allowed
Castings In Stressed Areas	10	10	10	Castings are not used
Shoulder Strap Pull-Off Angle	5	3	3	Shoulder strap pull-off angle less than desired zero degrees

CREW RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
Lapbelt Angle to Seat Cushion	5	5	5	Conforms to desired angle (45°)
Lapbelt Tiedown Strap	5	0	0	Not provided
Inertia Reel Types	5	5	5	MA-6 reel used is considered adequate
Depth of Structure Between Floor and Belly	10	5	5	18 to 24" of structure is provided in design. Shape is flat, however, crash tests have demonstrated reasonable crush capability
TOTAL	125	52	52	

TROOP RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
Vertical Energy Attenuator Capacity	30	0	0	No E/A provided
Restraint Webbing & Geometry	20	12	12	No shoulder harness No lapbelt tie-down strap Lapbelt strength not to desired minimums
Seat Longitudinal Strength	10	3	3	8G vs 30G desired minimum
Seat Lateral Strength	10	4	4	8G vs 20G desired minimum
Seat Vertical Strength	10	3	3	8G vs 25G desired minimum
Castings	10	10	10	Castings not used
Shoulder Strap Pull-Off	10	0	0	Shoulder harness not provided
Lapbelt	10	5	5	Lapbelt 24° vs 45° desired
Lapbelt Tiedown	5	5	5	No tiedown strap
Depth Structure	10	2	2	11" structure provided Flat shape
Total	125	44	44	

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
SPILLAGE CONTROL:				
FUEL CONTAINMENT				
Location	12	10	10	Saddle-mounted tanks are close to primary impact areas and occupied cabin. Tanks are reasonably remote from heavy masses and ignition sources. Crashworthy fuel cells mitigate potential hazard.
Vulnerability	12	10	10	Crashworthy system has been designed to control hazards associated with structural displacement. Landing gear failures do pose a hazard due to location.
Construction Techniques	30	30	30	Cells are regular in shape and conform to requirements of MIL-T-27422.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
Fuel Boost System	6	4	4	Cell-located, electrically driven boost pumps are used but are not sump located.
<u>OIL AND HYDRAULIC CONTAINMENT</u>	(INCLUDES RESERVOIRS, ACCUMULATORS, LINES AND COMPONENTS)			
Location	7	4	6	Generally, components are located well away from major impact areas. Demand-only utility hydraulics system on 'D' model mitigates problems of hydraulics in cabin area. Engine oil reservoir mounting on engine could be a hazard if engine were torn off in a severe crash. Integral lube system on 'D' model eliminates all but engine lube lines.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
Vulnerability	7	5	6	Component locations are generally in areas not subjected to major distortion in a survivable crash.
Construction Techniques and Tiedown Adequacy	6	4	4	Hydraulic components are adequately supported. Location and installation, design of fwd, aft, and combiner XMSNs are adequate. Cast housings of engine oil reservoirs are a hazard.
Flammable Fluid Lines	30	6	28	Integral lube system eliminates all but engine oil lines. Demand-only utility hydraulics and modular design minimize amount and criticality of hydraulic lines. Fuel lines are flexible, are designed to breakaway and seal at likely separation points, and

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
				are of self-sealing construction which is resistant to puncture.
Firewall	9	6	6	Since engines are located outside of, and high up on, fuselage, there is little danger of spilled fluid other than from engine sources from contacting hot engine parts, provided engines are retained on their mountings.
Fuel Flow Interruptors	9	5	8	Fuel flow interruptors are not used and with crashworthy fuel system design are not considered necessary. No effective improvement in control of hydraulic or lube oil hazards would be achieved through use of these type devices.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
IGNITION CONTROL				
Induction & Exhaust Flame Location	30	20	20	Engines are located above and behind fuel cells. Fuel mist created by leakage from ruptured tank would be likely to be either ingested into engine or ignited by exhaust. Crashworthy fuel cell construction mitigates hazards associated with location.
Hot Metals & Shielding	30	21	24	While mist can come into contact with engines, as noted above, aircraft would have to roll onto its side into spilled fuel for hot engine components to contact any fuel spilled onto ground during crash. APU location does not pose any particular

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
				hazards and is not likely to be on-line during a crash. Heater location is remote from fuel but leakage from hydraulic components could contact heater. On the 'D' model, these utility hydraulic systems are normally depressurized except when being used.
Engine Location & Tiedown	15	14	14	Engine separation from mounts during crash sequence could result in Engine/spilled fuel contact. Breakaway, self-sealing, flammable fluid lines are used at engine firewall interface to control leakage if engine does separate. Experience and crash test has shown that retention strength combined with inherent energy attenuation

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
				in aft structure is adequate to prevent engine separation during survivable CH-47 crash impacts.
Battery Location & Tiedown	12	10	10	Battery is located in left pod, fwd of front auxiliary fuel cell. Location next to fuel cell is not desirable. Crashworthy fuel cell design mitigates potential hazard.
Electrical Wire Routing	12	3	10	Wires have been relocated away from flammable fluid lines in tunnel and into fuselage. New location reduces probability of wires being cut due to a blade strike on tunnel area during a crash.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
				Wiring is routed sufficiently high in fuselage such that deformations of structure during a survivable crash should have little effect on line continuity.
Fuel Boost System	7	4	4	Electrically powered tank-mounted pumps are used. Pumps are located near bottom of cells.
Transformer Rectifier Location & Tiedown Strength	6	4	4	Units are located in fwd and aft fuel pods. Location next to fuel cells is not desirable. Crashworthy fuel cell design mitigates potential hazard.
Generator Location & Tiedown Strength	6	5	5	Generators are mounted off aft main transmission, in center of aft pylon. Operation and

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
				crash test data has shown that crash damage occurring in this area is not likely to result in generator retention failure during a survivable crash.
Lights Location & Tiedown Strength	5	4	4	Anti-collision light at STA 290, lower centerline and two controllable searchlights on underside of fuselage at STA 65 could become ignition sources during crash sequence. Anti-collision light at STA 290 is in area close to fuel cells. Crashworthy fuel cell design mitigates potential hazard.
Antenna Location & Tiedown Strength	4	3	3	Location of radar altimeter receiver, transmitter, ADF loop antennas, and the UHF-VHF

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
				communication antennas under the fuselage between the fuel cells is considered to be an ignition hazard. Crashworthy fuel cell design mitigates potential hazard.
Totals	255	172	210	

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
Crushing of Occupied Troop/ Passenger Areas	15	15	15	Distance from nose to first seat row is 10 feet which is considered adequate to prevent crushing during a survivable crash sequence.
Absence of Plowing	10	5	5	Underfloor structure is not designed to prevent plowing. Fwd sloping bulkhead at front end of cockpit floor could form a scoop and cause nose to dig in.
Resistance to Longitudinal Impact Loads	10	8	8	Fuselage design is rated very high from shear strength standpoint due to strong sidewall structure with only window openings; i.e., no large side doors. Underfloor structure lacks continuous longitudinal beams to control floor buckling.

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
Resistance to Vertical Impact Loads	20	15	15	Crash test has substantiated XMSN and engine retention capability in a survivable crash impact. Although designed only for an 8, 8, 8G static loading capability, they reacted crash load impulses up to 40G. Aft fuselage has shown a tendency to collapse under high vertical crash impact loads. This collapse occurs primarily in ramp area aft of main occupied cabin section.
Resistance to Lateral & Rollover Impact Loads	20	17	17	Fuselage section plus lack of large openings makes for high resistance to rollover loads. Seat location against sidewalls results in a definite hazard during a pure side impact. Side impacts are

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
				rare for this type helicopter.
Landing Gear Vertical Force Attenuation	20	7	7	Landing gear is designed to standard noncrashworthy criteria and is judged to be capable of attenuating a 12 fps impact velocity without fuselage contact. As 20 fps is desired, a rating of $(12/20)^2$ is assigned.
Landing Gear Location	5	3	3	Aft landing gear is clear of occupied area, however, fwd gear location does constitute a hazard to troops in immediately adjacent cabin area. This was demonstrated during NASA crash test.
Effect of Blade Strike	20	12	17	Blade penetrations into occupied areas can occur due

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
				to static forces acting on blades during impacts. Glass blades tend to fail "soft", be retained on their hub during impact loading, and are less likely to penetrate into occupied areas after damage.
Effect of Fuselage Fracture/ Separation	5	2	2	Crash tests showed beginnings of fuselage fracture/ separation at STAs 440 and 160 during NASA crash impact testing. Complete separation did not occur, however, both of these failure points are across seat rows.
Totals	125	84	99	

EVACUATION RATING

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
Ease & Reliability of Exit Operation	15	15	15	Pilot and copilot doors are designed for single action emergency release. Each of the three primary cabin emergency exits is operated by single action initiation. Possibility of jamming is remote as none of exits carries primary loads. Operational and test experience has shown trouble-free operation of emergency exits. In addition to primary emergency exits, each of the eight windows in cabin sides is jettisonable. An equal distribution of exits exists throughout aircraft.
Ratio of Usable Exits to Occupants	15	14	14	A ratio of one exit per 10 occupants is considered to be minimum acceptable.

EVACUATION RATING

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
				One primary exit per eleven cabin occupants is provided under worst conditions with eight additional window exits available under some conditions.
Availability of Exits in Rolled Aircraft	10	6	6	A minimum of one exit per 16.5 occupants is available vs one per 10 desired.
Identification of Exits	10	8	8	Exits are identified by one inch high letters and emergency lights are available over each exit. Placarding to instruct each passenger which exit to use is not provided.
Emergency Lighting	10	10	10	Emergency battery-powered, impact-actuated lights are provided at each primary emergency exit.
Totals	60	53	53	

INJURIOUS ENVIRONMENT RATING

SUBFACTOR	OPTIMUM NUMBER	CH-47C	CH-47D	REMARKS
Proximity of Cockpit Panels & Controls	10	9	9	Occupant restraint system provided is sufficient to prevent contact with cockpit panels and controls. Overhead circuit retention problem in earlier models has been corrected on 'D' model. Leg contact can occur with lower edge of instrument panel.
Anti-Torque Pedal Area	5	2	2	Crushing of lower nose structure could trap feet.
Absence of Injurious Objects in Cabin	5	3	3	Wall structure behind side-mounted troop seats presents a hazard in otherwise hazard-free cabin.
Retention of Interior Equipment	10	10	10	Equipment in immediate vicinity of occupants is restrained to recommended 25G.
Totals	30	24	24	

APPENDIX G

ACAP CRASHWORTHINESS EVALUATION SUMMARY

BASIC FACTOR	HAZARD POTENTIAL	OPTIMUM NUMBER	ACTUAL VALUE
Crew Retention System	17.92%	125	120
Troop Retention System	17.23%	125	120
Postcrash Fire Potential	35.19%	255	189
Basic Airframe Crashworthiness	17.23%	125	97
Evacuation	8.29%	60	60
Injurious Environment	4.14%	30	25
TOTAL	100%	720	611

CREW RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	ACAP	REMARKS
Vertical Energy Attenuating Capability	30	30	Pilot & copilot seats will conform to MIL-S-58095
Restraint Webbing Geometry & Strength	25	25	Will conform to MIL-S-58095 requirements
Seat Longitudinal Strength	10	10	Will conform to MIL-S-58095 requirements
Seat Lateral Strength	10	10	Will conform to MIL-S-58095 requirements
Seat Vertical Strength	10	10	Will conform to MIL-S-58095 requirements
Absence of Castings in Stressed Areas	10	10	No castings in stressed areas
Shoulder Strap Pull-Off Angle	5	5	Will conform to MIL-S-58095 requirements
Lapbelt Angle to Seat Cushion	5	5	Will conform to 45° to 50° requirements
Lapbelt Tiedown Strap	5	5	Will conform to MIL-S-58095 requirements
Inertia Reel Types	5	5	Will conform to MIL-S-58095 requirements
Depth of Structure Between Floor & Belly	10	5	Structural deformation marginal
TOTAL	125	120	

TROOP RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	ACAP	REMARKS
Vertical Energy Attenuator Capacity	30	30	Troop seats will conform to MIL-S-58095 (12" vertical stroke)
Restraint Webbing and Geometry	20	20	Will conform to MIL-S-58095 requirements
Seat Longitudinal Strength	10	10	Will conform to MIL-S-58095 requirements
Seat Lateral Strength	10	10	Will conform to MIL-S-58095 requirements
Seat Vertical Strength	10	10	Will conform to MIL-S-58095 requirements
Absence of Castings in Stressed Areas	10	10	No castings in stressed areas
Shoulder Strap Pull-off	10	10	Double shoulder straps will conform to 0° to 25° angle
Lapbelt Angle to Seat Cushion	10	10	Will conform (45° to 55° requirement)
Lapbelt or Side Tiedown Strap	5	5	Will conform to MIL-S-58095 requirement
Depth Structure Between Floor & Belly	10	5	Structural deformation for 95th percentile survivable accident is marginal
TOTAL	125	120	

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	ACAP	REMARKS
Fuel Containment	60	50	Fuel cell(s) would be relatively remote from engine and isolated from occupied areas. Fuel cell(s) and attachments shall conform to MIL-T-27422 and TR79-22E. Fuel cell material would be crash resistant, self-sealing
Oil and Hydraulic	20	15	All transmissions to have either integral lube or short lines. Tie-downs designed for crash survivable loads. Spillage could come into contact with hot surfaces or ignition sources
Flammable Fluid	30	20	Flammable fluid transfer within the aircraft has been minimized by using short line runs and integral lubrication. Fuel lines would be self-sealing with frangible self-sealing connectors
Firewall	9	9	Engine fire zones would be isolated by firewalls to prevent spreading of fire

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	ACAP	REMARKS
Fuel Flow Interruptors	9	9	Frangible self-sealing connectors are installed at all fuel cell connections and where fuel lines traverse engine bay firewalls.
<u>Ignition Control</u>			
Induction & Exhaust Flame Location	30	25	Engines are high above the ground and located above the crashworthy fuel cells. There is a possibility, in the event of fuel spillage, that fuel mist could be ingested
Location of Hot Metals and Shielding	30	28	Engines are located above fuel cells. Hence, low probability of spilled fluids contacting hot engine parts while aircraft remains upright. Firewalls would isolate spillage of flammable fluids on hot components.
Electrical Wire Routing	12	10	Sufficient length of wiring will be provided in potential ignition areas to allow for airframe deformation during crash without causing wire fractures.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	ACAP	REMARKS
Fuel Boost System	7	2	Boost system - self-sealing fuel lines would be installed
Transformer Rectifier Location & Tiedown Strength	6	6	Location would be away from fuel tanks. Tiedown will conform to crashload requirements
Generator Location and Tiedown Strength	6	6	Tiedown will conform to crashload requirements
Lights Location & Tiedown	5	5	Tiedown will conform to crashload requirements
Antenna Location & Tiedown Strength	4	4	Tiedown will conform to crashload requirements
TOTAL	255	189	

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	ACAP	REMARKS
Distance From Nose to Troop/Passenger Areas	10	8	Airframe structure is designed to the longitudinal impact conditions. Troop distance from nose is sufficient
Absence of Plowing	20	10	Nose has smooth contour.
Resistance to Longitudinal Impact Loads	10	8	Airframe structure is designed to the longitudinal impact conditions.
Resistance to Vertical Impact Loads	30	25	Structure will be designed to provide vertical load conditions.
Resistance to Lateral & Roll-over Impact Loads	20	16	Structure will be strengthened but total mission requirement will be difficult to meet.
Landing Gear Vertical Force Attenuation	20	17	Landing gear is designed to 20 fps without fuselage contact.
Landing Gear Location	5	3	Main gear is in good location but outboard of the fuel cell. Nose gear is in front of the crew member's legs.
Effect of Blade Separation on Cabin Occupants	5	5	Hazardous effect on occupants considered remote provided occupants remain in cabin

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	ACAP	REMARKS
Effects of Fuselage Fracture/Separation	5	5	Sufficient strength is in cabin area to stay intact in a crash condition
TOTAL	125	97	

EVACUATION RATING

SUBFACTOR	OPTIMUM NUMBER	ACAP	REMARKS
Ease & Reliability of Exit Operation	15	15	Will conform
Ratio of Usable Exits to Occupant	15	15	Ratio of occupants to usable exits is 2:1
Availability of Exits in Rolled Aircraft	10	10	Ratio of occupants to usable exits in a rolled aircraft is 4:1
Identification of Exits	10	10	Will conform
Emergency Lighting	10	10	If required, will conform
TOTAL	60	60	

INJURIOUS ENVIRONMENT

SUBFACTOR	OPTIMUM NUMBER	ACAP	REMARKS
Proximity of Cockpit Panels and Controls	10	8	Low probability of structural contact for cockpit occupants with lapbelt and shoulder harness, except for possible limb flailing under some crash conditions
Retention of Interior Equipment	10	10	Will conform to factors for mass item retention
Rudder Pedal Area	5	3	Crushed nose could trap pilot/copilot's feet
Absence of Injurious Objects in Cabin	5	4	Cabin would be designed with minimum protrusions.
TOTAL	30	25	

APPENDIX H

SCOUT CRASHWORTHINESS EVALUATION SUMMARY

BASIC FACTOR	HAZARD POTENTIAL	OPTIMUM NUMBER	ACTUAL VALUE
Crew Retention System	17.92%	125	125
Troop Retention System	17.23%	125	125
Postcrash Fire Potential	35.19%	255	217
Basic Airframe Crashworthiness	17.23%	125	125
Evacuation	8.29%	60	60
Injurious Environment	4.14%	30	27
TOTAL	100%	720	679

CREW RETENTION SYSTEM

SUBFACTOR	OPTIMUM NUMBER	SCOUT	REMARKS
Vertical Energy Attenuating Capability	30	30	Pilot & copilot seats will conform to MIL-S-58095
Restraint Webbing Geometry & Strength	25	25	Will conform to MIL-S-58095 requirements
Seat Longitudinal Strength	10	10	Will conform to MIL-S-58095 requirements
Seat Lateral Strength	10	10	Will conform to MIL-S-58095 requirements
Seat Vertical Strength	10	10	Will conform to MIL-S-58095 requirements
Absence of Castings in Stressed Areas	10	10	No castings in stressed areas
Shoulder Strap Pull-Off Angle	5	5	Will conform to MIL-S-58095 requirements
Lapbelt Angle to Seat Cushion	5	5	Will conform to 45° to 50° requirements
Lapbelt Tiedown Strap	5	5	Will conform to MIL-S-58095 requirements
Inertia Reel Types	5	5	Will conform to MIL-S-58095 requirements
Depth of Structure Between Floor & Belly	10	10	Structural deformation ample for 95th percentile survivable accident
TOTAL	125	125	

CABIN AREA
(TROOP RETENTION SYSTEM)

SUBFACTOR	OPTIMUM NUMBER	SCOUT	REMARKS
Vertical Energy Attenuator Capacity	30	30	Troop seats will conform to MIL-S-58095 (12" vertical stroke)
Restraint Webbing and Geometry	20	20	Will conform to MIL-S-58095 requirements
Seat Longitudinal Strength	10	10	Will conform to MIL-S-58095 requirements
Seat Lateral Strength	10	10	Will conform to MIL-S-58095 requirements
Seat Vertical Strength	10	10	Will conform to MIL-S-58095 requirements
Absence of Castings in Stressed Areas	10	10	No castings in stressed areas
Shoulder Strap Pull-off	10	10	Double shoulder straps will conform to 0° to 25° angle
Lapbelt Angle to Seat Cushion	10	10	Will conform (45° to 55° requirement)
Lapbelt or Side Tiedown Strap	5	5	Will conform to MIL-S-58095 requirement
Depth Structure Between Floor & Belly	10	10	Structural deformation for 95th percentile survivable accident is ample
TOTAL	125	125	

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	SCOUT	REMARKS
Fuel Containment	60	60	Fuel cell is remote from engine and isolated from occupied areas. Fuel cell and attachments conform to MIL-T-27422 and TR79-22E. Fuel cell material is crash resistant, self-sealing
Oil and Hydraulic	20	20	All transmissions to have integral lube. Tiedowns designed for 20G crash-survivable loads. Spillage will be confined away from hot surfaces or ignition sources
Flammable Fluid	30	25	Flammable fluid transfer within the aircraft has been minimized by using short line runs and integral lubrication. The use of a suction fuel system and frangible self-sealing connectors will minimize fuel spillage.
Firewall	9	9	Engine fire zones will be isolated by firewalls to prevent spreading of fire

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	SCOUT	REMARKS
Fuel Flow Interruptors	9	9	Frangible self-sealing connectors and installed at all fuel cell connections and where fuel lines traverse engine bay firewalls.
<u>Ignition Control</u>			
Induction & Exhaust Flame Location	30	28	Engines are high above the ground and located above the crashworthy fuel cells. In the event of fuel spillage, fuel mist will be confined away from induction and exhaust flame location.
Location of Hot Metals and Shielding	30	28	Engines are located above fuel cells. Hence, low probability of spilled fluids contacting hot engine parts while aircraft remains upright. Firewalls will isolate spillage of flammable fluids on hot components.
Electrical Wire Routing	12	10	Sufficient length of wiring will be provided in potential ignition areas to allow for airframe deformation during crash without causing wire fractures.

POSTCRASH FIRE POTENTIAL

SUBFACTOR	OPTIMUM NUMBER	SCOUT	REMARKS
Fuel Boost System	7	7	Suction feed system
Transformer Rectifier Location & Tiedown Strength	6	6	Location will be away from fuel tanks. Tiedown will conform to crashload requirements
Generator Location and Tiedown Strength	6	6	Tiedown will conform to crashload requirements
Lights Location & Tiedown	5	5	Tiedown will conform to crashload requirements
Antenna Location & Tiedown Strength	4	4	Tiedown will conform to crashload requirements
TOTAL	255	217	

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	SCOUT	REMARKS
Distance From Nose to Troop/Passenger Areas	10	10	Airframe structure is designed to the longitudinal impact conditions. Troop distance from nose is sufficient
Absence of Plowing	20	20	Nose has smooth contour. Anti-plowing design incorporated.
Resistance to Longitudinal Impact Loads	10	10	Airframe structure is designed to the longitudinal impact conditions.
Resistance to Vertical Impact Loads	30	30	Structure designed to provide vertical load conditions.
Resistance to Lateral & Roll-Over Impact Loads	20	20	Structure designed to provide lateral and rollover impact protection.
Landing Gear Vertical Force Attenuation	20	20	Landing gear is designed to 20 fps without fuselage contact.
Landing Gear Location	5	5	Main gear is in good location outboard of the fuel cell. Tail gear is located away from occupants and high cost components.
Effect of Blade Separation on Cabin Occupants	5	5	Hazardous effect on occupants considered remote provided occupants remain in cabin

BASIC AIRFRAME CRASHWORTHINESS

SUBFACTOR	OPTIMUM NUMBER	SCOUT	REMARKS
Effects of fuselage fracture/separation	5	5	Sufficient strength in cabin area to stay intact in a crash condition
TOTAL	125	125	

EVACUATION RATING

SUBFACTOR	OPTIMUM NUMBER	SCOUT	REMARKS
Ease & Reliability of Exit Operation	15	15	Will be provided
Ratio of Usable Exits to Occupant	15	15	Ratio of occupants to usable exits is 1:1
Availability of Exits in Rolled Aircraft	10	10	Ratio of occupants to usable exits in a rolled aircraft is 2:1
Identification of Exits	10	10	Will be provided
Emergency Lighting	10	10	Will be provided
TOTAL	60	60	

INJURIOUS ENVIRONMENT

SUBFACTOR	OPTIMUM NUMBER	SCOUT	REMARKS
Proximity of Cockpit Panels and Controls	10	8	Low probability of structural contact for cockpit occupants with lapbelt and shoulder harness, except for possible limb flailing under some crash conditions
Retention of Interior Equipment	10	10	Will conform to factors for mass item retention
Rudder Pedal Area	5	5	Crushed nose will not trap pilot/copilot's feet (15 ft/sec impact)
Absence of Injurious Objects in Cabin	5	4	Cabin would be designed with minimum of protrusions.
TOTAL	30	27	

APPENDIX I. ADDITIONAL SUPPORTING DATA FOR GENERATION OF COST ESTIMATING CURVES

TABLE I.1. OH-6 ACQUISITION COST SUPPORTING DATA

	BASELINE			IMPROVED		
	LBS.	$ PER LB.	$	LBS.	$ PER LB.	$
TOTAL AIRCRAFT	1499.1	-	$252,372	1802.1	-	$283,472
AIRFRAME	444.9	$141.81	$ 63,093	614.5	$141.81	$ 87,142
LANDING GEAR	80.0	$ 59.79	$ 4,783	114.1	$ 59.79	$ 6,822
SEATS						
CREW (1)	65.5	$ 50.00	$ 3,275	77.6	$ 50.00	$ 3,880
CREW (2)	-	-	6,550	-	-	7,760
TROOP (1)	8.65	$ 50.00	$ 433	11.17	$ 50.00	$ 559
TROOP (2)	-	-	866	-	-	1,118
FUEL SYSTEM (1)	36.0	$ 50.00	$ 1,800	107.0	$ 50.00	$ 5,350

(1) BASELINE = NON-CRASHWORTHY
IMPROVED = CRASHWORTHY

TABLE I.2. OH-58 ACQUISITION COST SUPPORTING DATA

	BASELINE			IMPROVED		
	LBS.	$ PER LB.	$	LBS.	$ PER LB.	$
TOTAL AIRCRAFT	1769.3	-	$288,398	2045.4	-	$319,443
AIRFRAME	475.7	$151.57	$ 72,100	642.1	$151.57	$ 97,323
LANDING GEAR	84.0	$ 59.52	$ 5,000	117.8	$ 59.52	$ 7,011
SEATS						
CREW (1)	63.6	$ 50.00	$ 3,180	75.0	$ 50.00	$ 3,750
CREW (2)	-	-	6,360	-	-	7,500
TROOP (1)	8.26	$ 50.00	$ 413	10.63	$ 50.00	$ 532
TROOP (3)	-	-	1,239	-	-	1,596
FUEL SYSTEM (1)	41.5	$ 50.00	$ 2,075	87.8	$ 50.00	$ 4,390

(1) BASELINE = NON-CRASHWORTHY
IMPROVED = CRASHWORTHY

TABLE I.3. UH-1 ACQUISITION COST SUPPORTING DATA

	BASELINE			IMPROVED		
	LBS.	$ PER LB.	$	LBS.	$ PER LB.	$
TOTAL AIRCRAFT	4673.4	-	$691,626	5110.0	-	$736,110
AIRFRAME	946.5	$182.68	$172,907	1115.4	$182.68	$203,761
LANDING GEAR	160.0	$ 55.49	$ 8,879	196.9	$ 55.49	$ 10,926
SEATS						
CREW (1)	62.4	$ 50.00	$ 3,120	74.6	$ 50.00	$ 3,730
CREW (2)	-	-	6,240	-	-	7,460
TROOP (1)	8.0	$ 50.00	$ 400	10.55	$ 50.00	$ 528
TROOP (11)	-	-	4,400	-	-	5,808
FUEL SYSTEM (1)	87.2	$ 50.00	$ 4,360	266.4	$ 50.00	$ 13,320

(1) BASELINE = NON-CRASHWORTHY
IMPROVED = CRASHWORTHY

TABLE I.4. AH-1 ACQUISITION COST SUPPORTING DATA

	BASELINE			IMPROVED		
	LBS.	$ PER LB.	$	LBS.	$ PER LB.	$
TOTAL AIRCRAFT	4878.7	-	$1,022,623	5239.3	-	$1,074,509
AIRFRAME	1137.5	$224.75	$ 225,656	1330.3	$224.75	$ 298,985
LANDING GEAR	175.6	$ 54.12	$ 9,504	206.5	$ 54.12	$ 11,176
SEATS						
CREW (1)	67.3	$ 50.00	$ 3,365	78.6	$ 50.00	$ 3,930
CREW (2)	-	-	6,730	-	-	7,860
TROOP (1)	9.01	$ 50.00	$ 451	11.38	$ 50.00	$ 569
TROOP (0)	-	-	0	-	-	0
FUEL SYSTEM (1)	82.3	$ 50.00	$ 4,115	197.4	$ 50.00	$ 9,870

(1) BASELINE = NON-CRASHWORTHY
IMPROVED = CRASHWORTHY

TABLE I.5. CH-47 ACQUISITION COST SUPPORTING DATA

	BASELINE			IMPROVED		
	LBS.	$ PER LB.	$	LBS.	$ PER LB.	$
TOTAL AIRCRAFT	20,890.4	-	$5,930,942	21,952.6	-	$6,062,622
AIRFRAME	4,509.8	$328.78	$1,482,736	4,785.5	$328.78	$1,573,377
LANDING GEAR	1,186.7	$ 80.00	$ 94,936	1,242.0	$ 80.00	$ 99,360
SEATS						
CREW (1)	64.8	$ 50.00	$ 3,240	78.6	$ 50.00	$ 3,930
CREW (2)	-	-	6,480	-	-	7,860
TROOP (1)	8.51	$ 50.00	$ 426	11.38	$ 50.00	$ 569
TROOP (33)	-	-	14,058	-	-	18,777
FUEL SYSTEM (1)	1,321.0	$ 50.00	$ 66,050	1,931.0	$ 50.00	$ 96,550

(1) BASELINE = NON-CRASHWORTHY
IMPROVED = CRASHWORTHY

TABLE I.6. OH-6 INJURY SEVERITY DISTRIBUTION BY CAUSAL FACTOR

	BASELINE			IMPROVED		
	FATALITIES	MAJOR	MINOR	FATALITIES	MAJOR	MINOR
PRIMARY STRUCTURE & LANDING GEAR	7	22	39	2	9	17
SEATS & RESTRAINT SYSTEMS	1	4	8	0	1	2
INTERNAL ENVIRONMENT	2	9	16	1	7	12
OPERATIONAL PROBLEMS	2	7	11	1	5	9
FIRE	9	0	0	0	0	0
NON-SURVIVABLE IMPACT	7	0	0	7	0	0
TOTAL	28	42	74	11	22	40
GRAND TOTAL	144			73		

TABLE I.7. OH-58 INJURY SEVERITY DISTRIBUTION BY CAUSAL FACTOR

	BASELINE			IMPROVED		
	FATALITIES	MAJOR	MINOR	FATALITIES	MAJOR	MINOR
PRIMARY STRUCTURE & LANDING GEAR	5	16	13	2	10	7
SEATS & RESTRAINT SYSTEMS	2	7	5	0	2	2
INTERNAL ENVIRONMENT	6	16	13	2	12	11
OPERATIONAL PROBLEMS	0	1	0	0	1	0
FIRE	14	0	0	0	0	0
NON-SURVIVABLE IMPACT	25	0	0	25	0	0
TOTAL	52	40	31	29	25	20
GRAND TOTAL	123			74		

TABLE I.8. UH-1 INJURY SEVERITY DISTRIBUTION BY CAUSAL FACTOR

	BASELINE			IMPROVED		
	FATALITIES	MAJOR	MINOR	FATALITIES	MAJOR	MINOR
PRIMARY STRUCTURE & LANDING GEAR	40	60	81	12	36	50
SEATS & RESTRAINT SYSTEMS	8	12	17	2	5	6
INTERNAL ENVIRONMENT	18	27	37	7	21	30
OPERATIONAL PROBLEMS	1	1	2	0	1	1
FIRE	22	0	0	0	0	0
NON-SURVIVABLE IMPACT	45	0	0	45	0	0
TOTAL	134	100	137	66	63	87
GRAND TOTAL	371			216		

TABLE I.9. AH-1 INJURY SEVERITY DISTRIBUTION BY CAUSAL FACTOR

	BASELINE			IMPROVED		
	FATALITIES	MAJOR	MINOR	FATALITIES	MAJOR	MINOR
PRIMARY STRUCTURE & LANDING GEAR	3	13	18	1	8	11
SEATS & RESTRAINT SYSTEMS	1	6	8	0	1	2
INTERNAL ENVIRONMENT	2	8	13	1	5	7
OPERATIONAL PROBLEMS	1	2	3	0	2	2
FIRE	10	0	0	0	0	0
NON-SURVIVABLE IMPACT	33	0	0	33	0	0
TOTAL	50	29	42	35	16	22
GRAND TOTAL	121			73		

TABLE I.10. CH-47 INJURY SEVERITY DISTRIBUTION BY CAUSAL FACTOR

	BASELINE			IMPROVED		
	FATALITIES	MAJOR	MINOR	FATALITIES	MAJOR	MINOR
PRIMARY STRUCTURE & LANDING GEAR	1	3	5	0	1	1
SEATS & RESTRAINT SYSTEMS	1	4	7	0	0	1
INTERNAL ENVIRONMENT	1	3	9	0	3	7
OPERATIONAL PROBLEMS	1	4	7	1	3	4
FIRE	8	0	0	0	0	0
NON-SURVIVABLE IMPACT	23	0	0	23	0	0
TOTAL	35	14	28	24	7	13
GRAND TOTAL	77			44		

TABLE I.11. OH-6 ESTIMATED COST OF INJURIES FOR 68 ACCIDENTS

	BASELINE			IMPROVED		
	FATALITIES	MAJOR	MINOR	FATALITIES	MAJOR	MINOR
PRIMARY STRUCTURE & LANDING GEAR	$1,515,920	$4,450,600	$872,898	$ 433,120	$1,820,700	$380,494
SEATS & RESTRAINT SYSTEMS	216,560	809,200	179,056	- 0 -	202,300	44,764
INTERNAL ENVIRONMENT	433,120	1,820,700	358,112	216,560	1,416,100	268,584
OPERATIONAL PROBLEMS	433,120	1,416,100	246,202	216,560	1,011,500	201,438
FIRE	1,949,040	- 0 -	- 0 -	- 0 -	- 0 -	- 0 -
NON-SURVIVABLE IMPACT	1,515,920	- 0 -	- 0 -	1,515,920	- 0 -	- 0 -
TOTAL	$6,063,680	$8,496,600	$1,656,268	$2,382,160	$4,450,600	$895,280
GRAND TOTAL	$16,216,548			$7,728,040		

TABLE I.12. OH-58 ESTIMATED COST OF INJURIES FOR 55 ACCIDENTS

	BASELINE			IMPROVED		
	FATALITIES	MAJOR	MINOR	FATALITIES	MAJOR	MINOR
PRIMARY STRUCTURE & LANDING GEAR	$ 930,760	$2,972,800	$260,936	$ 372,304	$1,858,000	$140,504
SEATS & RESTRAINT SYSTEMS	372,304	1,300,600	100,360	- 0 -	371,600	40,144
INTERNAL ENVIRONMENT	1,116,912	2,972,800	260,936	372,304	2,229,600	220,792
OPERATIONAL PROBLEMS	- 0 -	185,800	- 0 -	- 0 -	185,800	- 0 -
FIRE	2,606,128	- 0 -	- 0 -	- 0 -	- 0 -	- 0 -
NON-SURVIVABLE IMPACT	4,653,800	- 0 -	- 0 -	4,653,800	- 0 -	- 0 -
TOTAL	$9,679,904	$7,432,000	$622,232	$5,398,408	$4,645,000	$401,440
GRAND TOTAL	$17,734,136			$10,444,848		

TABLE I.13. UH-1 ESTIMATED COST OF INJURIES FOR 104 ACCIDENTS

	BASELINE			IMPROVED		
	FATALITIES	MAJOR	MINOR	FATALITIES	MAJOR	MINOR
PRIMARY STRUCTURE & LANDING GEAR	$6,512,120	$10,050,000	$1,418,310	$1,953,636	$6,030,000	$ 875,500
SEATS & RESTRAINT SYSTEMS	1,302,424	2,010,000	297,670	325,606	837,500	105,060
INTERNAL ENVIRONMENT	2,930,454	4,522,500	647,870	1,139,621	3,517,500	525,300
OPERATIONAL PROBLEMS	162,803	167,500	35,020	- 0 -	167,500	17,510
FIRE	3,581,666	- 0 -	- 0 -	- 0 -	- 0 -	- 0 -
NON-SURVIVABLE IMPACT	7,326,135	- 0 -	- 0 -	7,326,135	- 0 -	- 0 -
TOTAL	$21,815,602	$16,750,000	$2,398,870	$10,744,998	$10,552,500	$1,523,370
GRAND TOTAL	$40,964,472			$22,820,868		

TABLE I.14. AH-1 ESTIMATED COST OF INJURIES FOR 70 ACCIDENTS

	BASELINE			IMPROVED		
	FATALITIES	MAJOR	MINOR	FATALITIES	MAJOR	MINOR
PRIMARY STRUCTURE & LANDING GEAR	$ 780,000	$2,873,000	$ 450,000	$ 260,000	$1,768,000	$275,000
SEATS & RESTRAINT SYSTEMS	260,000	1,326,000	200,000	- 0 -	221,000	50,000
INTERNAL ENVIRONMENT	520,000	1,768,000	325,000	260,000	1,105,000	175,000
OPERATIONAL PROBLEMS	260,000	442,000	75,000	- 0 -	442,000	50,000
FIRE	2,600,000	- 0 -	- 0 -	- 0 -	- 0 -	- 0 -
NON-SURVIVABLE IMPACT	8,580,000	- 0 -	- 0 -	8,580,000	- 0 -	- 0 -
TOTAL	$8,580,000	$6,409,000	$1,050,000	$9,100,000	$3,536,000	$550,000
GRAND TOTAL	$20,459,000			$13,186,000		

TABLE I.15. CH-47 ESTIMATED COST OF INJURIES FOR 18 ACCIDENTS

	BASELINE			IMPROVED		
	FATALITIES	MAJOR	MINOR	FATALITIES	MAJOR	MINOR
PRIMARY STRUCTURE & LANDING GEAR	$ 136,015	$ 503,700	$ 87,830	$ - 0 -	$ 167,900	$ 17,566
SEATS & RESTRAINT SYSTEMS	136,015	671,600	122,962	- 0 -	- 0 -	17,566
INTERNAL ENVIRONMENT	136,015	503,700	158,094	- 0 -	503,700	122,962
OPERATIONAL PROBLEMS	136,015	671,600	122,962	136,015	503,700	70,264
FIRE	1,088,120	- 0 -	- 0 -	- 0 -	- 0 -	- 0 -
NON-SURVIVABLE IMPACT	3,128,345	- 0 -	- 0 -	3,128,345	- 0 -	- 0 -
TOTAL	$4,760,525	$2,350,600	$491,848	$3,264,360	$1,175,300	$228,358
GRAND TOTAL	$7,602,973			$4,668,018		

TABLE I.16. ESTIMATED STRIKE DISTRIBUTION BY CAUSAL FACTOR

	NUMBER OF ACCIDENTS	BASELINE			IMPROVED		
		NON-SURVIVABLE	FIRE	AIRFRAME & LANDING GEAR	NON-SURVIVABLE	FIRE	AIRFRAME & LANDING GEAR
OH-6	68	7	10	6.5	7	4.5	4.9
OH-58	55	21	2	9.5	21	.9	7.2
UH-1	104	20	19	10.5	20	8.6	7.7
AH-1	70	22	7	14.8	22	3.2	11.5
CH-47	18	5	9	.5	5	4.1	.4

1052-81